On the Non-Equivalence of Molecular Synthesis and Life Formation

Version 2 (Extended)

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Abstract

This paper establishes a formal non-equivalence between molecular synthesis and life formation, showing that they belong to fundamentally distinct classes of processes. Standard approaches to abiogenesis are typically framed in terms of constructing specific biomolecular structures under controlled conditions, implicitly assuming that constructibility implies relevance for natural emergence.

We show that this assumption is invalid: constructive accessibility does not imply environmental generability.

We propose that life should instead be understood as a self-sustaining transformation regime characterized by reproduction and transmission of structural organization. Within this formulation, individual molecular configurations are not primary. Rather, life corresponds to invariant classes of configurations under environment-dependent transformation dynamics.

This distinction is derived within the Filtered Configuration Framework (FCF), in which observable structures are treated as the result of successive filtering processes acting on a broader configuration space. As a consequence, molecular synthesis captures only a restricted projection of the generative process and cannot, by itself, establish relevance for life formation.

We further demonstrate that unstable and transient configurations, typically eliminated in controlled synthesis, play a functional role within transformation regimes by enabling coupling, redistribution, and the emergence of structural invariants. Functional organization is thus not tied to the stability of individual molecules, but to invariance at the level of transformation dynamics.

From this perspective, molecular implementations are non-unique: multiple configurations may realize the same functional role within an invariant regime. Therefore, commonly assumed prerequisites (e.g., specific molecular intermediates) are not ontological requirements, but contingent features of particular implementations.

This leads to a reformulation of abiogenesis: not as a problem of molecular construction, but as a problem of identifying transformation regimes and environmental conditions under which life-like organization emerges, persists, and reproduces.

Keywords: abiogenesis; origin of life; transformation regimes; structural invariance; reproduction; self-organization; molecular synthesis; environmental generability; Filtered Configuration Framework; Coherent Observational Epistemology

Contents

1 Introduction

The origin of life is commonly framed as a problem of spontaneous emergence under early Earth conditions. Standard approaches attempt to estimate the probability of forming complex biomolecular structures from simpler precursors within a given environment, often treating the observable biochemical landscape as representative of the underlying generative space.

This paper argues that such framing is incomplete.

More precisely, it rests on an implicit assumption: that the space of observable and constructible molecular configurations adequately represents the space of configurations that can be generated and sustained in natural environments. We show that this assumption does not hold.

We introduce the *Filtered Configuration Framework* (FCF), in which the observable set of structures is understood not as a direct reflection of generative possibilities, but as the result of successive filtering processes acting on a much larger configuration space. These processes include generation constraints, environment-dependent transformation, survival constraints, and observational (epistemic) constraints.

This perspective is consistent with Coherent Observational Epistemology (COE), which holds that all observations are produced through local interaction interfaces and are inherently constrained by the conditions of those interfaces [1]. Observability is therefore not a neutral window into reality, but a filtered projection determined by compatibility between the observer, the environment, and the configuration itself.

Within this framework, configurations are not treated as isolated objects, but as elements of environment-dependent transformation processes. In particular, molecular identities are not primary; what is fundamental are transformation regimes and the structural relations they sustain.

As a consequence, the central assumption of many abiogenesis models—that the space of observable structures reflects the space of possible generation pathways—no longer holds.

Instead, the observable biochemical domain is interpreted as a restricted subset shaped by:

- generation constraints (what can be formed),
- transformation processes (how configurations evolve within an environment),
- survival constraints (what can persist),
- observability constraints (what can be detected).

The Filtered Configuration Framework formalizes this structure through explicit operators and probabilistic representations, and demonstrates that:

- observability does not imply local generability,
- absence of configurations does not imply impossibility,
- and the current form of life reflects environmental filtering of transformation processes rather than the full space of possible biochemical realizations.

A key consequence of this framework is the non-equivalence between molecular synthesis and environmental generation. The ability to construct a molecule under controlled conditions does not imply its relevance or accessibility within an open transformation regime.

This reframes the problem of abiogenesis: from the question of how specific molecular structures were produced under particular conditions, to the more general question of how configurations are generated, transformed, filtered, and rendered observable across environments, and under what conditions transformation regimes capable of structural reproduction become invariant.

2 Definition: Life as a Transformation Regime

We define life as a transformation regime satisfying the following conditions:

- **Self-maintenance:** the system persists in a non-equilibrium state.
- **Reproduction:** structural organization is reproduced over time.
- **Transmission:** structural invariants are propagated across transformations.

Thus, life is not a property of individual configurations, but of a class of transformation regimes.

Remark. Self-organization alone is not sufficient. Systems such as convection exhibit structured patterns, but these are regenerated rather than inherited.

3 Theorem: Reproduction as Structural Invariance

Let T_E be a transformation regime over configuration space C. Let $\sim$ denote structural equivalence on C.

Definition. A regime is reproducing if there exists a subset $S \subset C$ such that:

$$T_E(S) \subseteq S$$

and:

- structural relations within S are preserved under iteration,
- for any $c \in S$, there exists a finite transformation sequence

  $$c \to \cdots \to c'$$

  such that $c' \in S$ and $c' \sim c$.

Theorem. A reproducing transformation regime defines an invariant class of configurations under iteration of T_E.

Interpretation. Life corresponds not to individual configurations, but to invariant subspaces of transformation dynamics.

Corollary (Failure of Non-Reproducing Systems). Let T_E be a transformation regime that produces observable structures but does not reproduce and transmit structural invariants.

Then T_E does not define a life-like regime.

Example (Convection). In convective systems, spatial structures (e.g., cells or rolls) emerge under energy flow and may persist over time. However, these structures are regenerated rather than reproduced.

There is no mechanism by which structural organization is transmitted as an invariant across transformations. Each instance arises from boundary conditions rather than from prior instances of the structure itself.

Conclusion. Convection exhibits self-organization but fails the criterion of reproduction and transmission. Therefore, it does not qualify as a life-like transformation regime.

4 Non-Equivalence of Molecular Synthesis and Life Formation

Let:

$$L : \varnothing \to c^*$$

be a laboratory synthesis process, and:

$$T_E : C \to \mathcal{P}(C)$$

an environmental transformation regime.

Then, in general:

$$c^* \in \mathrm{Im}(L) \ \not\Rightarrow \ c^* \in T_E$$

Proposition. Molecular synthesis is not invariant under transformation regimes.

5 Illustrative Transformation Regime

Consider a minimal chemical system:

$$\mathrm{CH_4},\ \mathrm{CO_2},\ \mathrm{N_2},\ \mathrm{H_2O} + \text{energy flux}$$

Representative transformations include:

- CH_4 → radicals → small hydrocarbons
- CO_2 → CO → H_2CO
- N_2 → NH_3 → HCN
- HCN + H_2CO → reactive intermediates

These processes lead to:

- heterogeneous mixtures of organics,
- cross-linked networks,
- tar-like phases,
- carbonization into soot and CO,
- nitrogen-rich residues and partial recycling.

Key Observation. The system preferentially produces sinks (tar, soot) rather than isolated intermediates.

These phases act as stabilizing matrices for transient configurations. Such phases provide heterogeneous environments with adsorption, confinement, and energy dissipation gradients that enable transient stabilization.

Emergence of Ribose as a Transient Pathway. Within such a transformation regime, oxygenated intermediates such as formaldehyde (H_2CO) and carbon monoxide (CO) accumulate alongside nitrogen-containing species (e.g., HCN) in a heterogeneous medium.

Under aqueous conditions, formaldehyde participates in self-condensation reactions:

$$n\,\mathrm{H_2CO} \;\rightarrow\; (\mathrm{CH_2O})_n$$

leading to the formation of simple sugars (formose-type chemistry).

In parallel, nitrogen-containing species (HCN and its derivatives) contribute to the formation of additional reactive intermediates, influencing the distribution and stability of resulting compounds.

A schematic pathway can be represented as:

$$\mathrm{H_2CO} \;\rightarrow\; \text{glycolaldehyde} \;\rightarrow\; \text{glyceraldehyde} \;\rightarrow\; \text{pentoses (including ribose)}$$

Important Qualification. This pathway does not represent a directed synthesis, but a transient branch within a broader transformation network.

The same regime simultaneously supports:

- decomposition of sugars,
- cross-reactions with nitrogen-containing species,
- incorporation into polymer-like and tar-like structures.

Role of the Medium. In isolation, ribose is chemically unstable. However, within heterogeneous phases (e.g., tar-like matrices, mineral-associated surfaces), transient stabilization becomes possible.

Thus, stability is not an intrinsic property of ribose as a molecule, but an emergent property of the surrounding transformation regime.

Conclusion. Ribose, if present, should be understood not as a privileged or primary product, but as a transient configuration embedded in a complex and continuously evolving chemical environment.

Ribose should be understood as a transient fluctuation within the regime rather than a primary generative unit.

6 Implication for Abiogenesis

Within such regimes, molecular instability does not imply irrelevance. Instead, unstable configurations actively contribute to ongoing transformation processes, acting as intermediates, catalysts, or structural precursors within a broader network.

Thus, the relevant question is not:

> Can a molecule be synthesized?

but:

> Does the transformation regime reproduce and propagate structural organization?

Shift of Perspective. This distinction reflects a deeper shift: from molecule-centered reasoning to regime-centered reasoning.

In standard abiogenesis approaches, molecules are treated as primary objects, and their successful synthesis under controlled conditions is taken as evidence of their relevance. Within the present framework, this inference does not hold.

A molecule may be:

- synthesizable in isolation,
- unstable in the relevant environment,
- or systematically removed by transformation dynamics.

Conversely, configurations that are never isolated or stable in pure form may still play a critical role as transient elements within a reproducing regime.

Non-Equivalence of Construction and Generation. Laboratory synthesis operates by:

- suppressing competing reactions,
- stabilizing intermediates,
- directing pathways toward a predefined target.

Environmental generation operates under fundamentally different conditions:

- competing pathways are active,
- intermediates are continuously transformed,
- no global target is specified.

Therefore, constructive accessibility does not imply environmental generability.

Reinterpretation of Instability. Instability, in this context, is not a failure mode but a functional property.

An unstable configuration may:

- enable coupling between otherwise disconnected pathways,
- facilitate energy dissipation,
- contribute to the formation of higher-order structures.

Thus, the elimination of unstable configurations in laboratory conditions may remove precisely those processes that are essential in natural regimes.

Implication for Target Molecules. Within this framework, molecules such as ribose should not be treated as primary targets of synthesis.

Instead:

- they may appear as transient configurations,
- their stability is environment-dependent,
- their relevance is determined by their role within a transformation regime.

Conclusion. Abiogenesis is not adequately described as the construction of specific molecules.

It is the emergence of transformation regimes that:

- sustain non-equilibrium organization,
- reproduce structural relations,
- and propagate invariants across transformations.

In this sense, life is not assembled but emerges as a stable mode of transformation.

7 Minimal Experimental Protocol

To test the hypothesis that life-like regimes arise from transformation dynamics:

- Open chemical system
- Continuous energy flux (UV, electrical, thermal gradients)
- Input mixture: CH_4, CO_2, N_2, H_2O
- No target molecules specified

Measurements:

- emergence of persistent cycles
- increase in structural connectivity
- recurrence of configuration classes
- persistence of structure across independent instantiations

8 Connection to FCF

Within the Filtered Configuration Framework (FCF)[2], observable structures are not direct reflections of generative possibilities, but outcomes of successive filtering processes acting on a broader configuration space.

Formally, the observable domain can be represented as the result of a filtering chain:

$$C \xrightarrow{G} C_G \xrightarrow{T_E} C_T \xrightarrow{S} C_S \xrightarrow{O} C_O$$

where:

- G denotes generation constraints,
- T_E denotes environment-dependent transformation,
- S denotes survival constraints,
- O denotes observability constraints.

Key Observation. These operators are not equivalent and, in general, do not commute. As a result, the observable set C_O is a structurally biased subset of the initial configuration space C.

Life as Invariance. Within this framework, life corresponds not to individual configurations, but to classes of configurations that remain invariant under the composite filtering operator:

$$F = O \circ S \circ T_E \circ G$$

That is, there exists a subset $S^* \subseteq C$ such that:

$$F(S^*) \subseteq S^*$$

and structural relations within S^* are preserved under repeated application of F.

Interpretation. Life corresponds to invariant subspaces of the filtering dynamics, i.e., to transformation regimes that survive generation, transformation, selection, and observation simultaneously.

Implication for Abiogenesis. From this perspective:

- the absence of a configuration in C_O does not imply its absence in C_G or C_T,
- successful synthesis corresponds only to inclusion in $\mathrm{Im}(G)$,
- but life requires invariance under the full operator F.

Thus, molecular synthesis addresses only a single stage of the filtering chain and cannot, by itself, establish relevance for life formation.

Reformulation. Abiogenesis should therefore be reformulated as the problem of identifying transformation regimes whose invariant subspaces persist under the full filtering structure of FCF.

Conclusion. Life is not a configuration selected from the space of possibilities, but a dynamically stable subset defined by invariance under generation, transformation, survival, and observation.

9 Non-Uniqueness of Molecular Implementations

A common implicit assumption in abiogenesis research is that specific molecular structures—such as ribose—constitute necessary prerequisites for life.

This assumption typically arises from laboratory synthesis, where the construction of RNA requires a sequence of well-defined intermediates:

$$\text{ribose} \rightarrow \text{nucleotide} \rightarrow \text{polynucleotide}.$$

This sequence is often interpreted as reflecting a natural generative order.

Methodological Origin of the Assumption. In controlled synthesis, target molecules are specified in advance. Reaction pathways are engineered to produce these targets by:

- suppressing competing reactions,
- stabilizing selected intermediates,
- enforcing a sequential construction order.

Within this framework, ribose appears as a necessary precursor. However, this necessity is conditional on the chosen construction method and target representation.

Non-Uniqueness of Implementation. Let $\mathcal{F}$ denote a class of functions corresponding to the reproduction and transmission of structural organization (as defined in Section 3).

Then, in general, there exists a family of realizations:

$$\mathcal{R} = \{r_i \mid r_i \text{ implements } \mathcal{F}\},$$

such that no single realization is uniquely required.

Thus:

$$\text{RNA} \in \mathcal{R}, \quad \text{ribose-dependent structures} \in \mathcal{R},$$

but:

$$\mathcal{R} \not\subseteq \{\text{ribose-based systems}\}.$$

Relation to Structural Invariance. From Theorem 3, life corresponds to invariant classes of configurations under transformation dynamics:

$$T_E(S) \subseteq S, \quad c \to \cdots \to c',\ c' \sim c.$$

This definition does not require preservation of specific molecular identity, but only preservation of structural relations up to equivalence.

Therefore, if two realizations $r_i, r_j \in \mathcal{R}$ satisfy:

$$r_i \sim r_j,$$

they belong to the same invariant class, even if their molecular composition differs.

Extension to FCF. Within the Filtered Configuration Framework, life corresponds to invariance under the composite operator:

$$F = O \circ S \circ T_E \circ G.$$

Thus, a realization r_i is relevant not because of its molecular form, but because it satisfies:

$$F(r_i) \subseteq r_i \quad \text{(up to structural equivalence)}.$$

Different molecular implementations may therefore correspond to the same invariant subset S^* under F.

Transformation Regime Perspective. In transformation regimes:

- configurations need not exist as stable, isolated entities,
- functional roles may be distributed across interacting components,
- persistence is defined at the level of invariance, not molecular identity.

In such regimes, ribose need not appear as a stable precursor. It may:

- appear transiently,
- be replaced by functionally equivalent configurations,
- or be absent from dominant transformation pathways.

Implication for Abiogenesis. The necessity of ribose is therefore not an ontological requirement of life, but a constraint of a particular biochemical implementation.

More generally, the inference:

$$\text{required in synthesis} \Rightarrow \text{required in nature}$$

does not hold.

Conclusion. The identification of specific molecules as necessary precursors reflects the structure of laboratory reconstruction rather than environmental generation.

Abiogenesis should therefore be framed in terms of identifying transformation regimes whose invariant classes persist under the full filtering operator F, rather than reconstructing specific molecular sequences.

Ribose as a Non-Invariant Configuration

Within the framework developed above, the relevance of a molecular configuration is determined not by its constructibility, but by its invariance under transformation dynamics.

Let $r_{\text{ribose}} \in C$ denote a configuration corresponding to ribose.

For r_{ribose} to constitute a necessary precursor within a life-like regime, it must satisfy invariance under the transformation regime T_E and, more generally, under the composite operator:

$$F = O \circ S \circ T_E \circ G.$$

That is, there must exist a subset $S^* \subset C$ such that:

$$r_{\text{ribose}} \in S^*, \quad F(S^*) \subseteq S^*,$$

and structural relations involving r_{ribose} are preserved (up to equivalence) under repeated application of F.

However, empirical and theoretical considerations indicate that ribose is chemically unstable in isolation and readily participates in competing reactions leading to decomposition or incorporation into alternative structures.

Thus, in general:

$$F(r_{\text{ribose}}) \not\subseteq r_{\text{ribose}},$$

and ribose does not define an invariant class under transformation dynamics.

Interpretation. Ribose, if present, does not act as a structurally preserved unit, but as a transient configuration within a broader transformation network.

Implication. The requirement that ribose must precede nucleotide or RNA formation presupposes invariance that is not supported by its transformation behavior.

Therefore, ribose cannot be treated as a necessary ontological precursor, but only as a contingent and non-invariant configuration within specific regimes.

Conclusion. From the perspective of structural invariance, ribose is not a defining element of life-like regimes, but a non-invariant intermediate whose presence or absence does not determine the existence of reproduction-capable transformation dynamics. In particular, molecules such as ribose do not define invariant classes and therefore cannot serve as necessary precursors in transformation-based models of life.

10 Epistemic Shift: From Molecules to Conditions

The preceding analysis implies a fundamental epistemic shift in how abiogenesis is approached.

Instead of seeking pathways for the synthesis of specific stable molecules (e.g., ribose), the focus must shift toward identifying the conditions under which transformation regimes emerge, persist, and reproduce structural organization.

Limit of Molecule-Centered Reasoning. Molecule-centered approaches assume that certain configurations are intrinsically fundamental and should therefore be directly constructed or stabilized.

However, within transformation regimes, such configurations are typically:

- transient,
- context-dependent,
- and embedded within larger reaction networks.

Ribose, for example, is not a structurally privileged endpoint, but a short-lived intermediate within a broader network of formation and decomposition processes.

From Targets to Regimes. The relevant objects of study are not target molecules, but:

- precursor configurations that enable network formation,
- successor (postcursor) configurations that result from transformation,
- and the environmental conditions that stabilize or recycle these processes.

Thus, the problem is not to isolate a molecule, but to characterize a transformation regime in which such configurations appear, transform, and contribute to structural propagation.

Stability as a Property of Conditions. In this framework, stability is not an intrinsic property of individual molecules, but a property of the environment and the transformation dynamics.

A configuration may be:

- unstable in isolation,
- yet recurrent and functionally persistent within a regime.

Therefore, the search for intrinsically stable molecules is replaced by the search for conditions under which instability becomes structured and productive.

Reformulated Objective. The objective of abiogenesis research should be reformulated as:

> Identification of environmental conditions and transformation regimes that generate, sustain, and reproduce structural organization across interacting configurations.

Conclusion. The shift from molecules to conditions dissolves the expectation that life must originate from the direct assembly of stable building blocks.

Instead, life emerges as a consequence of regimes in which transient configurations, including molecules such as ribose, participate in sustained and reproducing transformation processes.

11 Conclusion

Molecular synthesis and life formation are not equivalent.

The former concerns the construction of specific configurations under controlled constraints. The latter concerns the emergence of self-sustaining transformation regimes that reproduce and transmit structural organization.

Failure to recognize this distinction leads to systematic misinterpretation of experimental results in abiogenesis, where constructive accessibility is conflated with environmental generability.

Within the framework developed here, individual molecules do not define life. Rather, life corresponds to invariant classes of configurations sustained by transformation dynamics under environmental constraints.

In this sense, the instability of specific molecules does not invalidate their role, and their absence in isolation does not imply irrelevance within a regime.

Final Statement. This distinction is not methodological but structural. Abiogenesis is not a synthesis problem, but a regime selection problem. This shift replaces the search for molecules with the search for conditions under which life-like regimes become inevitable.

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