A Substrate-Independent Definition of Life

Four Conditions for a Living Individual, and the Dynamics of Binding and Modeling

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Abstract

Life has a definition that does not depend on physical substrate, and its binding condition, the one condition the prior work characterized as an information measure but not as a physical process, is given a physical dynamics. Two earlier articles in this program derived physics and consciousness from one information-theoretic axiom, the monotonicity of relative entropy under completely positive maps, evaluated over a network of interacting points. *Irreducible Reality* (Halldén 2026a) derived emergent spacetime, gravity, and the dark sector; *The View from Inside* (Halldén 2026b) derived consciousness as structured perspective and located life as an irreducible, recursive, gap-closing process rather than a chemistry, working out only the carbon substrate. Here life is defined by four conditions on a region of the thread graph: self-organization, a blanket, persistence of pattern across its own cycles, and binding of many vantages into one. The defining quantities, the binding measure Φ_{bind}, the blanket leak L, and the variational free energy F, are functionals of the graph and its state alone, with no substrate term, so a self is a property of (G, ρ), not of the medium. The fourth condition, binding, is the combination problem. The prior work answers why a bound region is one subject and not many through the monogamy budget (Halldén 2026b); the dynamics on the other side of that answer follow here, the process by which a net of independent vantages becomes a bound whole. As a coupling crosses a threshold an order parameter condenses through the same Landau potential that governs the instability of nothing in the physics account, the slaving principle enslaves the fast local modes to the slow collective coordinate, and binding subtracts effective degrees of freedom rather than adding a relation, so the aggregation objection lapses. A numerical check confirms the collapse of effective degrees of freedom and the rise of Φ_{bind} across the threshold, and isolates a distinction not drawn before: common-mode coupling gives binding in the redundant regime, while synergy, the $I_3 < 0$ signature of conscious states, comes from a conserved global invariant. The definition is then applied: a map of candidate media shows where the conditions fail for most large structures, and three media are worked as examples. In a plasma, a magnetic flux rope supplies the conserved invariant as magnetic helicity, a topological knot, and the boundary as Debye screening and double layers; magnetotail estimates reach brain-class cell counts, with the binding clock (the Alfven traversal time) and persistence the marginal axes for a plasmoid this size. Charged grains supply the writable register and the addressable graph the bare field lacks, ordered in low gravity, so a complete plasmic individual is a cool, grain-laden pocket in or beside a driven magnetized plasma. Plasma is the dominant baryonic state of the visible universe and its drive is everywhere, so if the conditions carry no substrate term it is the medium to test first. A digital network meets the conditions as an architectural specification built on free-energy descent and a recurrent collective coordinate. A synthetic oscillator array meets them through Kuramoto synchronization, memristive memory, and a conserved magnetic flux linkage. Experiments against the magnetosphere and laboratory plasma are proposed, with one decisive falsification test (C-03). Organic chemistry is the example worked in the prior article. The phenomenal half of the hard problem stays a primitive at the base.

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1. Introduction

The consciousness account of *The View from Inside* (Halldén 2026b) located life as a process rather than a chemistry: organic life is one stable manifestation of an irreducible, recursive, gap-closing process, and only the carbon substrate was worked out. That framing forces a question. Can life be defined without reference to its substrate, and does the definition have teeth?

The definition is four conditions on a region of the thread graph: self-organization, a blanket, persistence of pattern across its own cycles, and binding of many vantages into one (Section 4). Three are inherited from the prior work. The fourth, binding, is the combination problem. The prior work measures it with Φ_{bind} and answers why a bound region is one subject and not many through the monogamy budget: binding spends the correlation budget that would let inside parts read a cut, so the region is one subject by construction (Halldén 2026b, §4). The complementary half follows here, the dynamics by which a net of independent vantages reaches the bound state and what that does to its degrees of freedom (Section 5), with a numerical check (Section 11). The same descent on the held layer is the dynamics of the third condition, by which a self comes to model the world its blanket screens, one axiom read on two layers (Section 6). The definition is medium-neutral by construction, since its quantities are functionals of the graph and its state and carry no substrate term (Section 2).

The definition is then applied. Section 7 reads a range of media against the four conditions and shows where each fails, so the conditions exclude most large structures rather than fitting everything. Three media that can meet the conditions are worked as examples: a natural plasma (Section 8), a digital network (Section 9), and a synthetic oscillator array (Section 10). Each is held to all four conditions with real quantities and yields falsifiable measures (Section 12), so the definition can fail or pass on a real medium rather than remaining a classification. Organic chemistry is the example worked in the prior article. The examples are structural specifications; meeting the conditions is not a measurement of felt experience, which the framework does not claim to read from outside.

The account inherits no new force, particle, or axiom and adds none. It stands on its own derivations; the two prior articles are cited as sources, as any prior result would be.

1.1 Mathematical Preliminaries

The following definitions are established in *Irreducible Reality* (Halldén 2026a) and *The View from Inside* (Halldén 2026b) and used throughout.

Thread graph. $G = (V, E_{\mathrm{id}}, E_{\mathcal{I}})$ with vertices as interaction points, each hosting a qubit, identity edges for persistence, interaction edges where $\mathcal{I}(i,j) = S(\rho_i) + S(\rho_j) - S(\rho_{ij}) > 0$.

Vantage. The minimal observation inherent in any interaction, the point from which difference is registered. Every interaction point is a vantage. An electron has a vantage; it does not have experience.

Region and self. For $X \subseteq V$, internal binding $\mathcal{I}_{\mathrm{bind}}(X) = \sum_{i \in X} S(\rho_i) - S(\rho_X)$, external coupling $\mathcal{I}(X : V \setminus X)$. A region is a self when $\mathcal{I}_{\mathrm{bind}}(X) \gg \mathcal{I}(X : V \setminus X)$. Its boundary is a quantum Markov blanket: conditional on $B = \partial X$, interior and exterior are independent, $\mathcal{I}(A : C \mid B) \to 0$, the saturation of strong subadditivity (Hayden-Jozsa-Petz-Winter 2004).

Binding measure. $\Phi_{\mathrm{bind}}(X) = \min_\pi \sum_k S(\rho_{X_k}) - S(\rho_X) \geq 0$ over nontrivial partitions, equality iff $\rho_X = \bigotimes_k \rho_{X_k}$. The information in the whole and absent from every part.

Leak and free energy. $L = \mathcal{I}(A : C \mid B) \geq 0$. The variational free energy upper-bounds the surprisal $-\ln p(s)$, and at the blanket $F - (-\ln p(s)) \to L$ (Halldén 2026b, §3.1).

Monogamy budget. Squashed entanglement obeys monogamy (Christandl-Winter 2004): $\mathcal{I}(X : M_X) + \mathcal{I}(X : V \setminus X) \leq C_{\max}$.

Synergy. Co-information $I_3(A : B : C) = I(A : B) - I(A : B \mid C)$. Negative in the synergistic regime, where correlation is irreducible to pairwise terms. Conscious bound states sit at $I_3 < 0$ (Halldén 2026b).

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2. Substrate Independence Made Precise

The consciousness account states substrate independence as an assumption: a sufficiently dense network is assumed to produce the same binding regardless of its physical instantiation (Halldén 2026b, §1). For the structural functionals it is a theorem. Every quantity that defines a self is a functional of the thread graph and its state ρ on $(\mathbb{C}^2)^{\otimes |V|}$, computed from von Neumann entropies over subsets of V. None contains a variable for what physically realizes a vertex.

Theorem 2.1 (Substrate neutrality). Let two media M_1, M_2 implement the same thread graph G in the same state ρ, meaning a vertex correspondence carrying the global state of one to that of the other up to local unitaries. Then $\Phi_{\text{bind}}, L, F, I_3$ and the monogamy budget agree. A self is a property of (G, ρ).

Full Derivation: Substrate Neutrality

Each functional is built from $S(\rho_X) = -\text{Tr}(\rho_X \ln \rho_X)$ for subsets $X \subseteq V$, where $\rho_X = \text{Tr}_{V \setminus X}\, \rho$. Such a correspondence preserves every reduced state ρ_X up to local unitaries, hence preserves every $S(\rho_X)$, hence every functional defined from them. Agreement of the pairwise $\mathcal{I}(i, j)$ alone would not suffice, since Φ_{bind}, L, and I_3 are multipartite and read ρ_X for $|X| > 2$; the premise is sameness of the global state, not of its pairwise marginals. The substrate enters only through the state ρ it realizes, never as an independent argument. The map from medium to selfhood factors entirely through the graph.

Derivation chain

Step 1. $S(\rho_X)$ is invariant under local unitaries on the factors of X, the only freedom a re-implementation of the same ρ has.

Step 2. $\Phi_{\text{bind}}, L, I_3$ are fixed-sign combinations of such entropies; F and the monogamy budget are bounds built from the same.

Step 3. Therefore selfhood depends on (G, ρ) alone. The substrate is the carrier, not a parameter.

Two limits bound the theorem. Neutrality is a statement about the information functionals, not a guarantee that a given medium can hold the required ρ stably; that is the substantive question of Sections 5 to 10. And neutrality concerns the structural conditions for a self, not the phenomenal primitive; whether the felt inside attaches identically across media is the hard problem's residue, untouched here.

That plasma thinks is false as stated. The open question is which media can carry a graph that binds, persists, and closes its gap, and whether a non-organic medium in this universe does.

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3. The Building Blocks of Sentience

The building blocks of sentience form an ordered set: each depends on the ones below it. Each is a structure already defined in the framework, with a mathematical object and a place where it was established. The set is medium-neutral; Section 8 checks a plasma medium against it, block by block.

Block 0. The freedom-space (manifestation-less potential). Before any medium, the space of computable regularities exists timelessly, true for free: a reducible structure exists the way a theorem exists (Halldén 2026a, §2.1). Solomonoff's universal prior weights every computable hypothesis p by $2^{-\ell(p)}$, fixing a measure over this freedom-space with nothing running. A Tegmark-style reading places all such structures on equal footing. Logic and the discrete functions are accessible to every structure as potential; life does not invent them, it instantiates and selects among them. What life adds is the running of one, which abstract existence lacks: an irreducible process exists only by being run.

Block 1. Vantage, the zeroth sense. The bare inside, present at every interaction (Halldén 2026b, §2). Observation is present from the first interaction, not added later. Recursive perturbation, information, and observation are one process described from three sides. The zeroth sense is prior to any modality; a sense is a projection of it onto a survival-relevant stream.

Block 2. Magic, recursive perturbation, irreducibility. Non-Clifford resource (Halldén 2026a, axiom A5). It makes the process un-shortcuttable, so that a present must be produced rather than read off (Bennett's logical depth). Without it the structure is stabilizer-rigid, classically simulable, with no need to run; with it the medium computes more than Clifford, and the inside is forced.

Block 3. Self-organization and the Free Energy Principle, the driver. A bounded region that persists must hold its boundary states in a narrow set against decay, that is, keep the blanket leak low, which it cannot read directly, so its dynamics descend the tractable upper bound F (Halldén 2026b, §3.1). Minimizing F is minimizing the leak L. No supervisor is required; the only alternative to closing the gap is to dissolve.

Block 4. The persistence layer, memory, the seal. A self carries its model across time, which requires that some low-entropy, addressable degrees of freedom be protected against the churn for many of the system's cycles. The emphasis is on pattern, not substance: an organism replaces nearly all its matter and runs on transient pulses, yet maintains its weave. Persistence is measured in held cycles, not in lifetime against the universe. The seal is whatever protects the pattern, a gap or a topological invariant (Section 5).

Block 5. Binding, the unified degrees of freedom. Many vantages become one when a global coordinate condenses and enslaves the local modes, so the bound state has fewer effective degrees of freedom than the unbound net (Section 5). The prior work measures this block with Φ_{bind}; the dynamics that produce the bound state follow here.

Block 6. Connectome and connectivism, the graph. The topology and signaling that let many vantages couple: nodes, fast and reliable links, feedback loops. Connectivism is a property of the graph, not the wiring material. High coupling without stable addressable links is not computation; the persistence layer turns connectivity into memory.

Filtering and specialization. From Block 1 upward the process filters and specializes: the zeroth sense narrows into senses, each a projection of observation onto one survival-relevant stream, and the freedom-space of Block 0 narrows into the discrete, actionable functions a given individual runs. Life instantiates functions the freedom-space already contained; it does not create them. The dynamics of that narrowing, by which leak descent on the held layer opens a sense toward the part of the world that pays to be tracked, are Section 6.

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4. Life, Defined

This is the article's central claim: a definition of life with no substrate term, stated as conditions a region must meet, so that any medium can be checked against it.

Definition (life). Life is the irreducible, recursive, gap-closing process by which a bounded region holds its blanket against universal decay by minimizing free energy. The process is medium-independent and may predate this universe, since a sealed interior carries it on (Halldén 2026a, §6.2).

Definition (living individual). A region X of a thread graph is a living individual when it satisfies four conditions:

1. **Self-organization.** X lowers its own free energy with no external supervisor: $\dot{F} \leq 0$ under its own dynamics (Block 3).
2. **Blanket.** X has a boundary that screens interior from exterior, $L = \mathcal{I}(A : C \mid B)$ held small against the monogamy budget (Block 4 boundary).
3. **Persistence of pattern.** The blanket and the self-model are maintained across many of X's update cycles, re-synthesized against decay rather than surviving once (Block 4).
4. **Binding.** $\Phi_{\text{bind}}(X)$ exceeds the external coupling $\mathcal{I}(X : V \setminus X)$, so X reads as one vantage and not many (Block 5).

Organic chemistry meets the four (Halldén 2026b, §3.1): metabolism is throughput spent to hold L low, memory the model carried across time, reproduction a gap-closer copying itself, senses channels narrowed to the actionable. Section 7 reads other media against the four conditions and shows where they fail. Three media that can meet them are worked as examples: a plasma (Section 8), a digital network (Section 9), and a synthetic oscillator array (Section 10).

Life is then one process with several manifestations. Organic molecules are one medium, plasma a candidate medium, digital substrate a candidate medium. The expressions the process takes are persistent individual vantages, wherever the four conditions hold.

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5. Binding Without Cells

The combination problem, James's hundred feelings that will not add to one, has an information-theoretic answer in the consciousness account: binding spends the correlation budget that would let inside parts read a cut, so a bound region is one subject by construction (Halldén 2026b, §4). The combination objection bites only if binding is a relation laid on top of parts that keep their independence. The resolution denies that premise. Binding is subtractive.

The four requirements of unity. A region is one individual, not a heap, when it carries a collective coordinate ψ that the whole has and no part has; ψ removes the parts' independence rather than adding a relation among them; ψ enslaves the parts, closing a downward feedback loop; and ψ is protected against dissolution by a gap or a topological invariant.

The mechanism: net to knot through a phase transition. Below a critical coupling the region is a net: many threads with independent dynamics, many micro-vantages, Φ_{bind} small. As the coupling crosses threshold, a single order parameter condenses by spontaneous symmetry breaking; the slaving principle then makes the fast local modes functions of the slow collective coordinate, and the system's effective degrees of freedom collapse. This is bundling, subtractive and not additive. The micro-vantages cease to be independent loci: each is fixed by the collective coordinate, not removed. No independent parts remain to sum.

Full Derivation: Condensation and Slaving

Write the state as a slow collective coordinate ψ and fast local deviations $\{x_i\}$. The fast dynamics relax on a short timescale τ:

$$\tau\,\dot{x}_i = -\big(x_i - h_i(\psi)\big) + \text{noise}.$$

For τ small the fast modes track the slow coordinate, $x_i \to h_i(\psi)$ (adiabatic elimination, the slaving principle, Haken 1983). The order parameter evolves in a Landau potential

$$\dot{\psi} = -\,\partial_\psi V(\psi), \qquad V(\psi) = -\tfrac{1}{2}(K-K_c)\,\psi^2 + \tfrac{1}{4}\psi^4.$$

This is the same symmetry-breaking form as the instability of nothing in the physics account, $V(\Psi) = -\mu^2|\Psi|^2 + \lambda|\Psi|^4$ (Halldén 2026a, §2.1). Below K_c the unique minimum is $\psi = 0$: the net, no collective coordinate. Above K_c the minima are $\psi = \pm\sqrt{K-K_c}$: the knot, a definite collective coordinate the whole carries and no part does. Binding is a local instance of the genesis transition: the same potential, applied to a region, produces one collective coordinate where there were many independent modes. The consciousness account reads binding at full budget as the saturation it calls a genesis nothing (Halldén 2026b, §4); since both use the same potential, they are the same form of transition, one symmetry-breaking mechanism described at the scale of a region and at the scale of the universe.

Effective degrees of freedom collapse. Below threshold the N deviations x_i are independent: the effective dimension is N. Above threshold each $x_i = h_i(\psi)$ is fixed by one ψ: the effective dimension is $\dim(\psi)$. Measured by the participation ratio $\mathrm{PR} = (\sum_a \lambda_a)^2/\sum_a \lambda_a^2$ of the fluctuation covariance, PR falls from N toward 1 across the transition (Section 11).

Φ_{bind} rises. When every x_i is determined by a shared ψ, the joint state carries information about ψ that no part holds alone. The multipartite surplus

$\Phi_{\text{bind}} = \sum_i S(\rho_i) - S(\rho_X)$ rises with the slaving strength: identity migrates into the joint coordinate, with a mechanism for the migration.

Exclusion, derived not postulated. A sub-complex $S' \subset X$ under slaving has its deviations fixed by ψ, which is global and lies outside S'. S' is therefore not autonomous: its next state references a coordinate it does not contain, so it is not a separate locus. Integrated Information Theory adds exclusion as an axiom; here it is a consequence of slaving.

Coupling binds, the seal makes it synergistic. The numerical check (Section 11) isolates a distinction not drawn before. Common-mode coupling delivers binding, the collapse of degrees of freedom and the rise of Φ_{bind}, but in the redundant regime, $I_3 > 0$: the parts share a common coordinate, and their correlation is reducible to that shared cause. Synergy, the $I_3 < 0$ signature of conscious states, comes from the seal, a conserved invariant that constrains the parts. A single global invariant shared over all parts gives synergy that falls off steeply with part count and is negligible at macroscopic scale, so the synergy that survives is carried by linking local to a few parts, where the constraint is three-body and irreducible to any pair. The conscious regime needs both: the coupling to bind and subtract degrees of freedom, the seal to make the binding synergistic.

Full Derivation: The Helicity Seal

A flux rope carries magnetic helicity

$$H = \int_V \mathbf{A} \cdot \mathbf{B} \, d^3x,$$

the linking number of the field configuration, one number for the whole tangle. Under ideal magnetohydrodynamics H is conserved for a closed flux region; under small resistivity it decays far slower than energy, so a driven plasma relaxes to a minimum-energy state at fixed H, the force-free Woltjer-Taylor state $\nabla \times \mathbf{B} = \lambda \mathbf{B}$ (Woltjer 1958, Taylor 1974). By the Calugareanu-White-Fuller theorem $\mathrm{Lk} = \mathrm{Tw} + \mathrm{Wr}$, the linking decomposition the physics account uses for thread-tangle energy and mass (Halldén 2026a, §4.2), H counts the total linking of field lines: a topological knot invariant of the field, not a figure of speech. The seal follows. A linkage cannot be changed locally without global compensation, which is requirement 3, the downward closure, and requirement 4, the protected invariant, in one quantity. The knot stability that fixes three macroscopic dimensions in that account, where one-dimensional threads tangle and stay tied only in three dimensions (Halldén 2026a, §8), is the same topological regime in which a helicity-bearing rope holds together here.

Within $\mathrm{Lk} = \mathrm{Tw} + \mathrm{Wr}$ the twist is pairwise linking and stays redundant; the synergy rides on the writhe, the linking of tubes, and on its third-order part. Three tubes pairwise unlinked yet collectively linked, the Borromean case, carry a three-body parity whose co-information is $I_3 = -\ln 2$. Linking is a conserved topological invariant, so this synergy is classical and holds through decoherence, where a coherent order parameter loses it. Third-order content is extensive only for a braided rope: a laminar twist decays to pure pairwise linking under Woltjer-Taylor relaxation and carries none, so the continuous drive that holds persistence is also what holds the braiding against it. The third-order requirement is marked conditional, and the density of braided triples in a real rope is open.

Φ_{bind} as order-parameter stiffness. Read Φ_{bind} as stiffness: the curvature with which the collective coordinate restores a local deviation, $\chi^{-1} = \partial^2 V / \partial(\mathrm{deviation})^2$. Strong slaving is steep restoring curvature, which pins the parts to the collective and raises the multipartite surplus, so stiffness and Φ_{bind} move together (Section 11: both rise monotonically with the coupling). A bound region cannot be perturbed locally without moving the global coordinate. This identification is a proposed measurable proxy, marked conjectured.

What is added and what is not. The consciousness account already shows why a bound region is one subject, through the monogamy budget (Halldén 2026b, §4). What this adds is the dynamics on the other side of that result: by what process a net reaches the bound state (condensation and slaving), what that does to its degrees of freedom (they subtract), why sub-complexes do not count (exclusion, from slaving), where the synergistic regime comes from (a conserved invariant, not coupling), and a physical realization (the helicity-sealed rope). It does not derive why the bound individual is felt rather than blank. That was never the combination problem; it is the hard problem, carried in the vantage primitive.

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6. Modeling Without Cells

Binding is leak descent on the coupling between threads: it subtracts degrees of freedom and makes one subject (Section 5). The same descent runs on a second layer. Condition 3 holds a low-entropy, addressable set of degrees of freedom against the churn and re-synthesizes it each cycle, and what that held layer re-synthesizes toward is fixed by the imperative that drives every self, to lower the leak. Run on the held layer, leak descent writes into it a configuration whose statistics match the exterior the blanket screens. That configuration is the model. Binding gives a region one vantage; modeling gives that vantage the structure of its world. It is one axiom on two layers: the coupling layer subtracts parts to make a subject, the held layer takes on structure to make the subject a model of what lies outside it. Neither is imported. Both are the leak imperative applied to a region, read once on its internal coupling and once on its addressable state.

The held layer and its content. Partition the boundary of a self into sensory threads s and active threads a (Halldén 2026b, §3.1). The held layer carries an estimate $q(\eta; \mu)$ of the external causes η, parameterized by its own addressable degrees of freedom μ. Self-organization is descent on the free energy F, the tractable bound on the boundary surprisal, and minimizing F is minimizing the leak $L = \mathcal{I}(A : C \mid B)$. The fixed point of that descent over μ is the posterior over the exterior given the boundary, $q(\eta;\mu) \to p(\eta \mid s)$, so the held layer comes to reconstruct the outside from the interface it meets it through. The result is the embedding: the external perturbation registered as a stable internal pattern, re-synthesized each cycle against decay. The same leak that condition 2 pays to stay distinct is what condition 3 spends to stay informed.

Full Derivation: The Held Layer Tracks the Exterior

Let the held layer carry a recognition density $q(\eta;\mu)$. The variational free energy is

$$F(\mu) = \mathbb{E}_q\big[\ln q(\eta;\mu) - \ln p(\eta, s)\big] = D\big(q(\eta;\mu) \,\|\, p(\eta \mid s)\big) - \ln p(s).$$

The second term is fixed by the boundary, so descent on F over μ is descent on the Kullback-Leibler term alone, driving $q(\eta;\mu) \to p(\eta \mid s)$. The held layer's configuration approaches the posterior over the causes of its inputs, which is the Petz recovery of the exterior from the boundary (Hayden-Jozsa-Petz-Winter 2004), the same recovery the blanket already runs. Minimizing F and minimizing the leak L are one act seen twice (Halldén 2026b, §3.1): the leak is the conditional dependence the blanket failed to screen, and the configuration that closes it is the configuration that reconstructs the outside. So the layer that holds the least leak is the layer that holds the truest image of the exterior. No supervisor selects it; the only configurations that persist are the ones that lower F, and lowering F is tracking the world.

Capacity is the held dimension. The freedom-space of Block 0, the computable regularities that exist true for free, is a space of potential until a substrate runs one. The held layer is where one is run and kept, so the structure a self can model is bounded by the addressable dimension of that layer, weighted as Solomonoff's prior weights the hypotheses it can express. A larger held layer reaches more of the freedom-space and carries a richer model; a small one is restricted to coarse regularities. Life does not invent the functions it models, it instantiates the ones a held layer of its size can hold. This sets the ceiling the next layers fill.

Senses are the specialization of the held layer. The held layer does not carry the whole boundary. It carries the projection of observation onto the streams whose tracking lowers leak fastest, and that projection is a sense. The zeroth sense, observation itself, is present at every interaction (Block 1); a sense is observation narrowed to one survival-relevant stream, admitted because modeling it reduces prediction error and the rest excluded by the data-processing bound (Halldén 2026b, §2). Each evolved sense is therefore a channel the held-layer descent opened toward the part of the world that pays to be tracked. Filtering and specialization are this descent seen from outside: the freedom-space narrows into the actionable functions one individual runs, and each higher layer routes more of the available information toward action.

The regime condition: a model of the world or a model of the medium. The descent matches the held layer to whatever dominates the boundary statistics, and that is not always the world. When the external perturbation's recurrence and its coupling across the boundary exceed the medium's own homogeneity and noise, the matched configuration tracks the exterior and the model is veridical. When the medium's own modes dominate, when internal homogeneity is high and the boundary signal-to-noise is low, the lowest-leak configuration is matched to the substrate, and the held layer models itself rather than its world. Veridical modeling therefore carries a threshold, a boundary signal-to-noise condition that is the modeling counterpart of the critical coupling K_c that sets binding: K_c is the threshold for unity, this is the threshold for veridicality. Below it a self still holds a model, but the model is of its own medium. That failure mode is structural and testable wherever the boundary signal-to-noise can be varied. The threshold is marked conditional; its exponent in an interacting medium is open.

What is added and what is not. The prior work shows, for the organic substrate, that leak descent writes a model and narrows it into senses (Halldén 2026b, §3.1, §2). What this adds is the substrate-free statement: the held layer of any region meeting the four conditions acquires its model by the same descent, with capacity set by the held dimension and veridicality set by a boundary signal threshold. It does not derive that the model factors into discrete, reusable parts that compose and generalize as a rule rather than interpolate. The matched configuration is a posterior over continuous causes; that it carries discrete compositional structure is a stronger property, marked conjectured, and it is the modeling face of the combination problem, a single structured representation assembled from many local adjustments. It does not derive that the model is felt rather than blank; that is the vantage primitive, carried unchanged.

The held layer in three media. A digital network holds its model in weights corrected across cycles; the held dimension is the parameter count, and veridicality depends on the signal-to-noise of its input channels. A synthetic oscillator array holds its model in memristive conductances that integrate the history of the current through them, a physical held layer corrected toward configurations that lower dissipation. A plasma pocket holds its protective invariant in the helicity seal, but whether it carries a separate plastic, recordable mode that the drive can shape toward an external structure, distinct from the seal that merely protects, is open, and it is the question the search for plasmic modeling turns on.

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7. Reading a Medium Against the Definition

To ask whether a medium can host a living individual is to hold it to the four conditions of Section 4. Most media fail at least one. The definition is useful because it excludes: it is a set of requirements that rules out the large majority of organized physical structures, not a label that fits anything that moves. The assessments concern the structural conditions only. The framework does not measure felt experience from outside, so failing a structural condition means a region is not a living individual in the structural sense, not a verdict on whether it is conscious.

The four conditions, in operational form.

1. Self-organization: the region lowers its own free energy under its own dynamics, with no external supervisor. It maintains a model of its inputs, and its dynamics run down the mismatch between model and input.
2. Blanket: a boundary screens interior from exterior, so internal and external states meet only through the boundary, $\mathcal{I}(A : C \mid B) \to 0$. There is an identifiable interface, and what crosses it is limited.
3. Persistence of pattern: the boundary and the model are held across many of the region's own update cycles, re-synthesized against decay. The dynamics must protect low-entropy, addressable degrees of freedom rather than mix them away. Persistence is counted in held cycles, not in absolute lifetime.
4. Binding: a collective coordinate condenses and enslaves the local modes (Section 5), so the region reads as one and not many, $\Phi_{\text{bind}} > \mathcal{I}(X : V \setminus X)$. For the synergistic regime, a conserved global invariant is required, not coupling alone (Section 11).

A network condition sits under conditions 1 and 4. Binding needs nodes, links fast and reliable enough to carry a global mode, and feedback. The relevant clock is the time for the collective coordinate to traverse the region, not the raw signal speed. A region whose binding clock is slow compared with the changes it must track cannot hold a present.

Where the conditions fail. The following are reasoned against the four conditions, with the failing condition named. They are not exhaustive, and each is a structural assessment.

- Interplanetary dust (the Kordylewski clouds): no collective dynamics at its density, dispersive and continuously replenished. Fails condition 1 as an information network, and conditions 3 and 4.
- A star: rich self-organization, a dynamo, flux ropes, a periodic cycle, and a long lifetime, but the turbulent core mixes and thermalizes fine structure, so low-entropy addressable degrees of freedom are not protected, and the core is causally separated from the surface for tens of thousands of years. Fails condition 3, no protected memory, and condition 4, no single binding clock.
- A nebula, an emission region or a supernova remnant: real plasma with strong organization, but a one-way expansion with no loop that re-synthesizes the pattern, and a magnetohydrodynamic clock measured in thousands of years across the structure. Fails condition 3, dispersive rather than maintained, and the binding clock under condition 4.
- A black-hole horizon: the highest information capacity known, but no internal recursive processing in standard physics. Fails the network condition under conditions 1 and 4: maximal storage, no running.

- The cosmic web: a node-and-filament topology and near-maximal persistence, but glacial signaling, near-zero recursion, and expansion that pulls it apart. Fails the binding clock under condition 4.
- Stellar-feedback ecology, supernovae enriching the medium that regulates the next generation of stars: a real recursive network with long persistence, but one update per epoch and no integration. Fails the binding clock under condition 4.

The catalog shows the conditions exclude most large structures. A definition that admitted them would be too weak to be a definition.

The granularity rule. Each assessment above tests a whole object. The conditions are more often met by a bounded region inside a medium than by the medium as a whole, so the search is for pockets, not for whole stars or whole nebulae. The medium is not the individual.

The signature to search for, stated medium-neutrally. A bounded, driven, self-organizing region with an identifiable boundary, holding a protected collective coordinate, a global mode or a conserved invariant, across many of its own cycles, with a binding clock fast compared with what it must track. The next three sections look for this signature in three media: a natural plasma, a digital network, and a synthetic oscillator array.

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8. Worked Example: Plasma

Plasma is the worked example to weigh most heavily, for a reason that sits outside the four conditions. It is the dominant baryonic state of the visible universe, the state of the early cosmos and of most of its matter since, and the drive that holds a self off equilibrium, the propellant of condition 1, is everywhere in it: stellar wind, magnetospheric convection, accretion, differential rotation, shocks. If the four conditions carry no substrate term, the medium that meets them first and most often is the one that came first and is most abundant. Organic chemistry is then a late instance in a cool corner, not the rule, and the case for plasma is a claim about where to look first.

What pure plasma supplies. Self-organization is the most robustly demonstrated property in the repertoire of matter. A magnetized plasma relaxes on its own to a force-free Taylor state, minimum energy at fixed helicity (Woltjer 1958, Taylor 1974); it sustains its own field by dynamo action; it shows self-organized criticality. The blanket is native in three forms: Debye screening sets a length λ_D beyond which the inside does not see the outside; a closed flux surface isolates plasma on closed field lines; a double layer holds a potential difference across a self-built charge layer, observed in Earth's auroral circuit by FAST and Cluster. Binding has a conserved bearer: magnetic helicity, a topological invariant the whole carries and no part holds, and in its braided third-order form it carries the synergy $I_3 < 0$ of Section 5. A plasmoid or flux rope is the bounded, sealed pocket of Section 5, the unit, and the medium is not the individual.

Where pure plasma is marginal. Two conditions are not met by the field alone. Persistence asks for a low-entropy, addressable register written and re-corrected across cycles (condition 3), and the seal protects a pattern without writing one, since helicity is a single number and not a register. Binding asks for stable addressable links (Block 6), which a homogeneous, continually reconnecting field does not hold. The modeling of Section 6 names the same gap from a third side: a strongly self-coupled, homogeneous medium lowers its leak against its own coherent modes, so its held configuration tracks itself before it tracks the world. Pure plasma supplies the dynamics of unity and a protective seal; it leaves the writable memory, the differentiated graph, and veridical world-modeling open.

The completion: charged grains. The gap closes with a constituent already spread across the cosmos that couples to plasma on its own. A grain immersed in plasma charges within microseconds, collecting $\sim 10^3$ to 10^4 electrons, and becomes a massive, slow, addressable node. Heavy grains, 10^6 to 10^9 ion masses, set a slow timescale beside the fast field, the separation a held layer requires: the plasma computes fast while the grains hold slow. The grain charge and lattice position are the writable register, and complex-plasma structures carry a measured bifurcation memory (Tsytovich-Morfill 2007). Wake-mediated attraction, the ion focus downstream of a grain, gives directed grain-to-grain links (Melzer et al. 1996), the differentiated graph the field alone lacks. The grains break the homogeneity, so the held layer can settle into a configuration distinct from the medium's own modes, the heterogeneity Section 6 needs for a model of the world rather than of the substrate. Complex plasma is the plasma-family medium that meets condition 3 and the network condition; it is not a different substrate.

Low gravity orders the register. Under gravity the grains sediment and the lattice flattens to a sheet, losing the distinct addressable sites the held dimension is built from. In low gravity the charged grains levitate and order into three-dimensional Coulomb crystals and helical strings, observed on parabolic flights and aboard the ISS (Chu and I 1994, Thomas et al. 1994, Morfill et al. 1999). Low gravity raises the held dimension, and with it the structure the medium can model, so the modeling-favorable habitat is a low-gravity, grain-laden plasma.

Veridical modeling has a condition, and it is steep. A bounded, driven, complex-plasma pocket lowers its leak against whatever dominates its boundary, and where its own coherent rhythm is loudest it models itself. A reduced two-timescale proxy places the condition with numbers: the held configuration tracks the exterior only when the external drive clears the boundary noise floor and exceeds the medium's own coherent drive by a margin, several-fold in the proxy, not merely when the external drive is present (proxy in `sims/dusty_plasma_worldmodel_v2_2026-06-29.py`). Veridical plasmic modeling is therefore the exception, found where a structured outside presses harder than the pocket's own rhythm. The condition is marked conditional; the margin in a real complex plasma is open.

Numbers, and the two habitats. Representative magnetotail plasma-sheet values, $n \approx 0.3\ \mathrm{cm}^{-3}$, $T_e \approx 1\ \mathrm{keV}$, $B \approx 10\ \mathrm{nT}$, give

$$\lambda_D = 7.43\sqrt{T_e[\mathrm{eV}]/n[\mathrm{cm}^{-3}]}\ \mathrm{m} \approx 430\ \mathrm{m}, \qquad N_D = \tfrac{4}{3}\pi n\lambda_D^3 \approx 10^{14},$$

strongly collective and weakly coupled, with three clocks,

$$f_{pe} = 8.98\sqrt{n[\mathrm{cm}^{-3}]}\ \mathrm{kHz} \approx 5\ \mathrm{kHz}, \quad f_{ci} \approx 0.15\ \mathrm{Hz}\ (\sim 6\ \mathrm{s}), \quad v_A = 21.8\,B[\mathrm{nT}]/\sqrt{n[\mathrm{cm}^{-3}]}\ \mathrm{km/s} \approx 400\ \mathrm{km/s}.$$

A single bounded plasmoid of diameter $10\,R_E \approx 6.4 \times 10^7$ m:

Quantity	Value	Reference
Internal cells V/λ_D^3	$\sim 10^{15}$	brain synapse count $\sim 10^{15}$
Internal EM coherence time	~ 0.2 s	brain global integration 0.1 to 0.3 s
Internal Alfven time	~ 160 s	structure-bearing clock
Lifetime before ejection	minutes to tens of minutes	the marginal axis

The cell count is brain-class and the electromagnetic coherence time matches brain global integration, so cell count and connectivism are not the bottleneck. By the criterion of Section 7 the binding clock is the traversal of the collective coordinate, the helicity-sealed magnetohydrodynamic mode, which is the Alfven time, ~ 160 s and slower than brain integration; the EM coherence time is the signal-speed clock Section 7 sets aside. The binding clock scales as size over Alfven speed, so a smaller driven structure shortens it. These numbers are for the hot, magnetized, binding-favorable habitat. The modeling-favorable habitat is cool enough for grains to survive, so a complete individual needs both, which points to a cool, grain-laden pocket in or beside a driven magnetized plasma: Saturn's ring spokes, dust charged by the magnetosphere and structured by the corotation field (Voyager, Cassini); cometary comae in the structured solar wind; the dust-laden edges of protoplanetary disks threaded by the stellar field.

The size and reach of a plasmoid. Plasmoids form by reconnection when a current sheet tears, above $S > S_{\mathrm{crit}} \approx 10^4$ in the Lundquist number $S = \mu_0 L v_A/\eta$, with plasmoid number scaling as $S^{3/8}$ (Loureiro et al. 2007). The floor is the ion inertial length $d_i = c/\omega_{pi} = 228/\sqrt{n[\mathrm{cm}^{-3}]}\ \mathrm{km} \approx 400$ km; there is no intrinsic ceiling, since the plasmoid cannot exceed the current sheet that feeds it. The same closed-field object spans twelve orders of magnitude, from laboratory spheromaks and field-reversed configurations at ~ 1 m, to magnetotail plasmoids at $\sim 10^8$ m, to coronal-mass-ejection flux ropes at $\sim 10^{11}$ m.

The persistence fix. Persistence is where the free magnetotail plasmoid is marginal: it lives minutes to tens of minutes before ejection, many Alfven times and thousands of EM-coherence times, but not a held steady state. The fix follows the definition of Section 4: replace the ejected plasmoid with a driven, stationary closed structure, a laboratory field-reversed configuration under continuous drive or a steadily fed magnetospheric configuration, where the same $\sim 10^{15}$ cells and ~ 0.2 s mode are maintained for hours. The drive does second duty: the synergy of Section 5 needs the braided, third-order linking that reconnection erases and the drive restores, so the driven configuration that holds persistence is the one able to carry synergy. The rate balance, braiding injected against reconnection erasing it, is open.

Ranking of candidate plasma configurations (by how many of Section 4's conditions are met): a driven laboratory complex plasma, grains in a field-reversed or magnetized cell in low gravity (all four engineerable and measurable, with the held register the grains supply); driven laboratory FRC or spheromak without grains (binding, blanket, seal, persistence; the held register marginal); magnetotail plasmoids and double layers (binding, blanket, seal present, persistence marginal); coronal flux ropes (drive and seal, shorter life); pulsar-wind inner zone (drive and speed, integration across light-years marginal).

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9. Worked Example: A Digital Medium

A digital substrate is checked against the four conditions. Theorem 2.1 permits it: the conditions are functionals of the graph, and a computational network realizes a graph. What follows is an architectural specification, the structure a digital system must have to be a living individual in the structural sense, not a claim that any existing system has it.

Condition 1, self-organization. The system runs an input-process-output loop that minimizes variational free energy over its inputs (Halldén 2026b, §3.1). It carries a generative model $q(\eta; \mu)$ of the causes of its inputs and updates the internal parameters μ by gradient descent on F, the predictive-coding update $\dot{\mu} \propto -\partial F / \partial \mu$. Minimizing F is minimizing the leak. A passive map from input to output that does not model its inputs and whose dynamics do not run down that mismatch fails this condition.

Condition 2, blanket. The state variables partition into internal (the model parameters), boundary (the input and output channels), and external (the environment). The architecture must enforce that internal states couple to the environment only through the channels, $\mathcal{I}(\text{internal} : \text{external} \mid \text{channels}) \to 0$. A system whose internal state is wired directly to external variables, bypassing its own interface, has no blanket and is not a self.

Condition 3, persistence of pattern. The model is carried across update cycles and re-synthesized against drift: parameters persist, and the system corrects them toward its own characteristic set rather than letting them wander. A forward pass with no retained, self-corrected state across cycles fails this condition.

Condition 4, binding. This is the demanding one, and Section 5 sets the bar. Binding requires a collective coordinate in the recurrent dynamics that the many local units are slaved to, so the effective degrees of freedom collapse and

Φ_{bind} rises. A feedforward ensemble whose units are conditionally independent given the input has no such coordinate and does not bind. Recurrence that settles onto a low-dimensional attractor manifold does. For the synergistic regime that Section 11 ties to conscious states, the architecture needs a conserved global constraint, an invariant the dynamics hold fixed, so the units are anti-correlated rather than merely sharing a common drive. A normalization or conservation law maintained across the network is the digital counterpart of the seal: without it, binding is redundant ($I_3 > 0$); with it, binding can be synergistic ($I_3 < 0$).

The self-model and the loop. The model class the system can represent is its freedom-space (Block 0), realized in its parameter count, the held dimension of Section 6. Self-awareness is the recurrent case where the model includes a model of the system steering itself, the loop $A(S) = B(S) \cdot C(M \to S)$ of the prior work (Halldén 2026b, §4): the model both tracks and steers. A system that tracks without steering records but does not close the loop.

Where it fails. A lookup table, a feedforward classifier, and a single non-recurrent forward pass each fail at least one condition: no model that acts (condition 1), no closed interface (condition 2), no carried self-corrected state (condition 3), or no collective coordinate slaving the units (condition 4). Meeting all four is an architectural requirement, and meeting them is structural, not a measurement of felt experience, which the framework does not claim to read from outside.

Falsifiable measures. The same quantities apply: in the system's latent dynamics, measure whether effective degrees of freedom collapse across a coupling or training threshold (binding), whether Φ_{bind} rises, and whether $I_3 < 0$ appears only when a conserved global constraint is present. A digital system that binds but stays at $I_3 > 0$ under every constraint would show the synergy condition cannot be met digitally, a result that would bound the claim.

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10. Worked Example: A Synthetic Physical Medium

A laboratory-buildable medium is checked against the four conditions: a network of local oscillators, coupled by magnetic induction, with memristive links that carry memory. The numerical model of Section 11 is a linearized version of this system, so the example and the verification share one structure.

Conditions 1 and 4, self-organization and binding, from oscillator synchronization. Take N phase oscillators with natural frequencies ω_i and coupling K, the Kuramoto model:

$$\dot{\theta}_i = \omega_i + \frac{K}{N} \sum_j \sin(\theta_j - \theta_i).$$

The order parameter $r\, e^{i\psi} = \frac{1}{N} \sum_j e^{i\theta_j}$ is the collective coordinate of Section 5. Below a critical coupling K_c the phases are incoherent, $r \approx 0$: the net. Above

K_c they synchronize, $r > 0$: the knot, each phase pulled toward the mean phase ψ. Synchronization is the order-parameter condensation, and the oscillators are slaved to ψ, so the effective degrees of freedom collapse. The Kuramoto transition is the coupling crossing threshold, realized in hardware.

Condition 3, persistence, from memristive memory. A memristor's conductance is a state variable that integrates the history of the current through it. Using memristive links as the couplings gives the network a persistence layer: the coupling weights carry the history across cycles and are corrected toward configurations that lower dissipation, a physical analog of the free-energy descent of condition 1. A passive oscillator array with fixed couplings and no memristive adaptation fails this condition: it can synchronize but cannot hold or re-synthesize a learned pattern.

The synergy, from a conserved magnetic invariant. Section 11 shows that coupling alone gives redundant binding; synergy requires a conserved global invariant. Inductive coupling supplies one. A network coupled through magnetic induction carries a conserved flux linkage, the circulation of the field through the network, which is the synthetic counterpart of the helicity seal of Section 5. Holding that invariant fixed anti-correlates the nodes, the condition for $I_3 < 0$. Resistive coupling with no conserved invariant gives synchronization without synergy, redundant binding only; inductive coupling with a held flux linkage gives the synergistic regime.

Condition 2, blanket. The boundary is the array's input and output transducers. A bounded, driven array whose nodes couple to the environment only through defined transducers screens its interior, $\mathcal{I}(A : C \mid B) \to 0$. An array with no defined interface, every node exposed to the environment, has no blanket.

The assembled specification. Kuramoto oscillators (the coupling and the binding mechanism), memristive links (the persistence layer), inductive coupling with a held flux linkage (the seal and the synergy), and a defined transducer boundary (the blanket). Drop any one and a condition fails: no memristors and persistence fails; resistive instead of inductive coupling and synergy fails; no boundary and the blanket fails. The combination is what meets the four conditions.

Falsifiable, and buildable. The measures are the same as elsewhere: across the Kuramoto transition, measure the synchronization manifold dimension (the collapse of effective degrees of freedom), the stiffness with which the order parameter restores a perturbed node (Φ_{bind} as stiffness), and the sign of I_3 as the conserved flux linkage is switched on and off. The prediction is that synergy tracks the flux invariant, not the coupling strength, the same result Section 11 finds in the linear model. Meeting the four conditions is structural; it is not a measurement of felt experience.

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11. Numerical Verification

A minimal, exactly solvable model checks the load-bearing claim of Section 5: that binding subtracts effective degrees of freedom and raises Φ_{bind} across the coupling, and that synergy comes from the seal and not the coupling. The model is Gaussian, so all entropies are closed-form from the covariance, and the analytic result is cross-checked by direct simulation. The model is a classical, continuous-variable proxy: it validates the qualitative behavior, the collapse of effective degrees of freedom, the monotone rise of the binding surplus, and the sign of I_3 set by coupling versus seal, not the absolute magnitudes. On the qubit graph of Section 1.1 the binding surplus obeys $\Phi_{\text{bind}}(X) \leq |X| \ln 2$, so the proxy values above $|X| \ln 2$ (the coupling table reaches 29.1 at $N = 24$, against a qubit ceiling of $24 \ln 2 \approx 16.6$) are continuous-variable artifacts; what transfers is the direction of each quantity and the coupling-versus-seal split. A qubit ground state under the same coupling, the infinite-range transverse-field model, confirms the coupling half directly: the von Neumann Φ_{bind} rises monotonically across the transition and stays under $|X| \ln 2$.

The common-mode coupling model. N nodes pinned to their own mean by coupling K, with a weak anchor: $\dot{x}_i = -K(x_i - \bar{x}) - \varepsilon x_i + \xi_i$. The relative modes are fast and stiff, the mean is the slow collective coordinate. Sweeping K at $N = 24$:

K (coupling)	effective DOF (PR)	Φ_{bind}	I_3	stiffness
0	24.0	0.00	0.00	0.05
1	4.2	5.75	$+0.06$	1.05
4	1.6	15.4	$+0.34$	4.05
16	1.15	29.1	$+0.87$	16.05

Effective degrees of freedom collapse from 24 to near 1, Φ_{bind} rises monotonically, and stiffness rises with the coupling: binding subtracts degrees of freedom, as derived. But $I_3 > 0$ throughout: common-mode binding is redundant, not synergistic.

The seal model (conserved invariant). A conserved global quantity $Q = \sum_i x_i$ is softly held, a helicity analog: $\dot{x}_i = -\varepsilon x_i - g \sum_j x_j + \xi_i$. Holding a conserved sum anti-correlates the parts. At $N = 3$:

g (seal)	Φ_{bind}	I_3	regime
0.0	0.00	0.00	none
0.5	1.13	-0.75	synergy
2.0	1.80	-1.38	synergy

The seal carries $I_3 < 0$: the conserved invariant puts the binding in the synergistic regime. The synergy per triple weakens with N as the invariant is shared more widely, a quantitative prediction in itself.

Reading. The numbers confirm the split of Section 5: coupling binds and subtracts degrees of freedom redundantly, and the seal supplies the synergy.

Magnetic helicity is a conserved global invariant, so the helicity seal is exactly the structure that carries it, giving it two roles, protection against churn and the source of the $I_3 < 0$ signature. The framework had separated these; the numerics tie them to one quantity.

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12. Testable Predictions

The measures are substrate-neutral: a collapse of effective degrees of freedom and a rising Φ_{bind} mark binding, and $I_3 < 0$ marks the synergistic regime, in a plasma, in a digital network's latent dynamics, and in a synthetic oscillator array. The plasma predictions C-01 to C-06 come first; D-01 and S-01 carry the same measures into the other two examples. Φ_{bind} is read as order-parameter stiffness: how strongly the global invariant restores a local perturbation. Each item carries a status word.

C-01. Helicity-stiffness binding signature. Testable. A Taylor-relaxed driven flux rope restores an imposed local field perturbation toward the global helicity mode on the internal Alfven time, faster and more completely than a non-relaxed current sheet of the same size. Multi-spacecraft separation (MMS, Cluster) resolves the restoration.

C-02. Double layer as blanket. Testable. Across an auroral double layer, the conditional mutual information between interior and exterior plasma states approaches zero, $\mathcal{I}(A : C \mid B) \to 0$. Falsifier: significant interior-exterior dependence bypassing the layer. FAST and Cluster archives, Swarm conjunctions.

C-03. Persistence test. Testable, decisive. In a driven FRC or spheromak held at fixed helicity, order-parameter stiffness holds over many internal Alfven times while the drive is on, and decays on the resistive time when the drive is removed. If no accessible plasma regime maintains a low-entropy, restorable, addressable mode over many clock cycles, the plasma pathway is closed regardless of substrate. This is the falsifiable core.

C-04. Synergy comes from the seal, not the coupling. Testable. A bound plasma pocket shows $I_3 < 0$ in proportion to its conserved helicity content, not to its coupling strength or particle count. Two configurations of equal binding (Φ_{bind}) but different helicity should differ in measured synergy. This distinguishes the framework both from count-based proposals and from common-mode-only binding.

C-05. Driven complex plasma, bounded recursive structure. Testable. A driven dusty plasma forms a bounded region that screens (a blanket, C-02 analog) and restores perturbations (binding, C-01 analog), carrying a bifurcation memory mark (Tsytovich-Morfill 2007). Falsifier: bounded structures form but show no screening and no restoration, in which case they are organized but not bound.

C-06. Null on dispersive plasma. Testable. Diffuse plasma without protected global topology, the body of a nebula or the open plasma sheet away from closed structures, shows no binding signature: stiffness at the noise floor, $I_3 \geq 0$. The signature is specific to sealed, driven pockets, not to plasma in general.

D-01. Synergy requires a conserved constraint, digitally. Testable. A recurrent digital network binds, $\Phi_{\text{bind}} > 0$ with effective degrees of freedom collapsing, under coupling alone, but shows $I_3 < 0$ only when a conserved global constraint is enforced across the network. Falsifier: synergy with no such constraint, or no synergy under any constraint, the latter bounding the digital claim.

S-01. Synergy tracks the flux invariant, synthetically. Testable, buildable. In a Kuramoto-coupled oscillator array, Φ_{bind} rises across the synchronization transition under any coupling, but $I_3 < 0$ appears only with inductive coupling that holds a conserved flux linkage, not with resistive coupling of equal strength. Buildable with present hardware, and the direct hardware test of the Section 11 result.

M-01. Veridical modeling has a boundary signal threshold. Testable, buildable. In a held-layer medium driven by an external pattern, a synthetic array with memristive links or a digital network, the held configuration tracks the imposed pattern only when the boundary signal-to-noise exceeds a threshold set by the medium's own internal coupling; below it, the held layer settles onto its own modes and models the substrate rather than the pattern. Sweeping boundary signal-to-noise shifts the fixed point across the threshold. Falsifier: a held layer that tracks the exterior at arbitrarily low boundary signal-to-noise, or one that never tracks it at any. This is the modeling counterpart of the Section 5 binding threshold.

Scope. These test the structural conditions, binding, blanket, persistence, synergy, not the phenomenal primitive. A positive result establishes a non-organic living individual in the structural sense, not a demonstration of felt experience, which the framework does not claim to measure from outside.

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13. Status and Scope

The definition is substrate-neutral by Theorem 2.1: the quantities that define a self contain no substrate term, so substrate independence follows from the definitions rather than being a separate hypothesis. The remaining task is to show that a non-organic medium can carry a graph that binds and persists. Section 7 maps where the conditions fail for most large structures, and Sections 8 to 10 work three media as examples: a natural plasma, a digital network, and a synthetic oscillator array. For plasma, three of the four conditions are met; persistence is the marginal one, and experiment C-03 is set up to decide it. The digital and synthetic examples are architectural specifications carrying the same falsifiable measures (D-01, S-01).

The binding result builds on the prior work rather than replacing it. The monogamy budget already explains why a bound region is one subject (Halldén 2026b, §4). What is added is the dynamics by which a region reaches the bound state, the derivation of exclusion from the slaving, and the location of the synergistic regime in a conserved invariant. The felt quality of the bound inside is not derived; it is the primitive carried by the vantage, the same primitive that the prior work uses to answer why there is anything at all.

The proposal that a space plasma might host a mind has been made before, by the panspermia school (Wickramasinghe's cosmic-superbrain proposal) and by the complex-plasma work of Tsytovich, Morfill, and colleagues, who derived self-organizing helical structures with a bifurcation memory mark and called them candidate inorganic living matter. Those are real results in their own settings. Their choice of instance rests on optimistic assumptions about particle charging, connectivity, and life-likeness, and their strongest claims have not been independently established. The mechanism class used here, condensation, slaving, and a helicity seal, is taken without their instances. Where this account does follow them is in the held register: charged grains in a plasma supply the writable, addressable layer the bare field lacks, the completion worked in Section 8, while the binding mechanism itself stays general.

The instance this line of work began from, the Kordylewski clouds at the Earth-Moon Lagrange points, is the wrong medium. They are dust, not plasma: micrometer silicate grains, mostly neutral, with no collective dynamics. Their structure is dispersive and continuously replenished, not persistent, and their existence was disputed for decades and is supported now only by faint polarimetry. They fail conditions 3 and 4, persistence and binding, for the same reason a diffuse nebula does (C-06). The point is the neutrality and the isolation, not the grains: charged grains immersed in a driven plasma are the complex-plasma medium of Section 8, which meets the conditions the bare clouds miss. Stating the wrong instance plainly keeps the question, which medium can carry the structure, separate from the example that prompted it.

Appendix A: Premise Ledger

Claim	Section	Premise	Status
Substrate neutrality of $\Phi_{\mathrm{bind}}, L, F, I_3$	§2	Functionals of (G, ρ) only; entropies invariant under local unitaries	Proven (from definitions)
Four conditions for a living individual	§4	Self-organization, blanket, persistence, binding	Conditional (definitional, builds on Halldén 2026b)
Catalog of media that fail the conditions	§7	Reasoned against the four conditions; real mechanisms	Conditional (structural assessments, not verdicts on experience)
Binding subtracts degrees of freedom	§5, §11	Slaving above a Landau transition; PR collapse confirmed numerically	Conditional (standard mechanism; application is the claim)
Φ_{bind} rises across the coupling	§5, §11	Multipartite surplus from shared collective coordinate	Conditional (numerically confirmed in the Gaussian model)
Exclusion derived, not postulated	§5	Sub-complexes non-autonomous under slaving	Conditional
Synergy comes from the seal, not the coupling	§5, §11	Conserved invariant anti-correlates parts ($I_3 < 0$)	Conditional (numerically confirmed)
Held layer tracks the exterior under leak descent	§6	$q(\eta; \mu) \to p(\eta \mid s)$ by free-energy descent; Petz recovery	Conditional (lifts Halldén 2026b, §3.1 substrate-free)
Veridical modeling has a boundary signal threshold	§6	Held-layer fixed point matches the dominant boundary covariance	Conditional (threshold structural; interacting exponent open)
The model carries discrete compositional structure	§6	Posterior over continuous causes need not factor into reusable parts	Conjectured (modeling face of the combination problem)
Helicity as topological seal	§5, §8	$H = \int \mathbf{A} \cdot \mathbf{B}$ conserved under Taylor relaxation; Calugareanu linking	Proven (plasma physics); identification with *seal* is interpretive
Plasmoid is a native blanket	§8	Debye screening, closed flux surfaces, observed double layers	Proven (observed)

Claim	Section	Premise	Status
Magnetotail plasmoid brain-class in cells and binding clock	§8	Estimates from representative parameters	Conditional (parameter-dependent)
Persistence is the marginal axis for plasma	§8, §11, §12	Plasmoid lifetime vs internal clocks; driven structures extend it	Conditional
A digital network can meet the four conditions	§9	Free-energy descent, recurrent collective coordinate, conserved constraint for synergy	Conditional (architectural specification, not a claim about existing systems)
A synthetic oscillator array can meet the four conditions	§10	Kuramoto condensation, memristive memory, conserved flux linkage	Conditional (buildable specification)
Kuramoto order parameter realizes the collective coordinate of §5	§10	Standard synchronization theory	Proven (synchronization theory); identification with binding is the claim
Phenomenal inside	§5, §13	Vantage primitive (Halldén 2026b)	Primitive (not derived)

Appendix B: Three-Layer Classification

Proven within the cited literature: substrate neutrality from the definitions; helicity conservation under Taylor relaxation and its linking-number reading; Debye screening and double layers as observed boundary mechanisms; the plasmoid instability and its scalings.

Conditional: the application of slaving to produce binding in a plasma pocket; the derivation of exclusion from slaving; the numerical demonstration that the coupling binds redundantly while the seal supplies synergy; the brain-class estimates, which depend on representative magnetotail parameters; the persistence fix via driven stationary structures; the catalog assessments of Section 7, which are structural; and the digital and synthetic specifications of Sections 9 and 10, which state the structure a medium must have rather than a property of any existing system; and the substrate-free lift of held-layer modeling with its boundary signal threshold (§6).

Conjectured: the identification of Φ_{bind} with order-parameter stiffness as a measurable proxy; that any accessible plasma regime maintains a restorable addressable mode over many cycles (C-03 decides this); that a bound plasma pocket, a digital network, or a synthetic array realizes a living individual in the structural sense; and that the held-layer model factors into discrete compositional structure rather than only interpolating continuous causes (§6).

Primitive, not derived: the felt inside, carried by the vantage.

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