

Life as Bounded Relational Dynamics

A Constitutive and Operational Synthesis for Mammalian Physiology

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October 2026 · Preprint manuscript

Abstract

What does the life of a mammalian cell, organ or organism consist in? A material inventory is insufficient: components turn over during continued life, organism-level integration may fail while many components remain intact, and local cells can remain viable after the larger individual dies. We defend a **constitutive, scale-declared interpretation**: the actual living process of a mammalian system is its materially realized, selectively bounded and self-maintaining relational dynamics, not a separate entity produced by those dynamics. The argument is one of comparative explanatory adequacy, not a novel necessary-and-sufficient classifier. The strongest competing account treats life as a physical disposition or capacity to sustain and resume characteristic functions, a problem already examined in general disposition metaphysics and in cryptobiosis literature. We distinguish current enactment of organized activity from physical organization preserving the capacity to reactivate it: vitrified embryos provide a limiting case. During deep storage, ordinary embryo-scale developmental activity is strongly suppressed while the physical prerequisites for reactivation can remain, just as a dry river channel can permit renewed flow when suitable conditions return. This distinction permits suspended viability without positing the uninterrupted operation of physiological metabolism. A compact state–relation formalism separates measured physical states from effective causal couplings and makes explicit their joint, history-dependent change, while remaining a coarse model, not a whole-animal simulator. Mammalian intestinal barriers and exercise-induced skeletal-muscle adaptation anchor the analysis. Existing process ontology, autopoiesis, constraint closure, relational biology and physiological control theories anticipate much of the proposal; an original empirical advantage is not claimed. The paper’s contribution is a bounded explanatory reconstruction and an explicit discipline for applying it.

Keywords: life; process ontology; relational dynamics; physiological organization; causal boundary; viability; disposition; mammalian biology; scale; adaptation.

1. Introduction: what the term ‘life’ refers to

An organism is material, but the inventory of its current material constituents is not an adequate description of what is going on when it lives. Molecules enter and leave, cells may die or be replaced, tissues repair their structures, and organs exchange materials, mechanical influences and signals. The continued life of the animal is bound up with the organized *activity* of this changing arrangement.

The core thesis is **constitutive** rather than productive. We are not proposing that physical dynamics manufacture an additional ingredient, force or object called life. Rather, for a known living mammalian system, **its actual living process is the materially instantiated pattern of activity and relations through which it operates and helps sustain itself**. A mathematical representation is a useful description of that process, not another living object.

Three issues must remain distinct: (a) **what actual biological living activity consists in**; (b) **which physical configurations retain the capacity to sustain or restart it**; and (c) **whether an individual is numerically the same across time and possible interruptions**. The third problem, and the clinical criteria of death,

cannot be settled by a short ontology paper. The second is essential, however, because a plausible theory must accommodate reversible physiological silence.

Our empirical domain is humans and other mammals. Intestinal barrier physiology and skeletal-muscle adaptation supply the principal mechanistic cases. We do not offer a universal definition applicable to every possible substrate, or infer that a computational expression alone is alive.

The relevant predecessors are extensive. Dupré and Nicholson (2018), Nicholson (2018) and DiFrisco (2018) articulate process-centered biological ontology; Maturana and Varela (1980) develop autopoiesis; Montévil and Mossio (2015), Moreno and Mossio (2015) and Mossio et al. (2016) formalize or develop the maintenance of constraints and organization; Rosen (1991) builds relational accounts of metabolism and repair. This paper does not assign priority to itself for their major ideas. It asks whether a physically explicit, scale-declared reconstruction makes the target of a life-as-process claim clearer and provides usable constraints on mechanistic explanation.

2. A positive argument: why prioritize a process over an inventory, property or extra product?

2.1 A comparative explanatory argument

Consider five observations, chosen because they expose the limits of the simplest candidates without already presupposing a universal definition of life.

P1 — Material turnover with continued living functioning. A mammal's constituents are continually exchanged or renewed, while its organized physiology can continue. A fixed-component account must add an account of ongoing organization. A process account treats turnover as part of the ongoing material activity, rather than a paradox to explain away.

P2 — Loss of organism-level function before total chemical destruction. After a profound loss of integrated physiological function, many material constituents initially remain present. The causal organization and its activity cannot be inferred from composition alone. This must not be confused with the temporary absence of a pulse: clinically determined death is not simply an instant in which one measured variable is zero.

P3 — Continued local living activity after whole-organism death. Some cells and tissues can retain viability when the whole-animal system has irreversibly ceased to function. Attribution must therefore specify the relevant scale and form of integration. Both process and sophisticated property theories can accommodate this fact.

P4 — Similar observed states, different future responses. Two states with similar routine measurements can respond differently because relevant microstates, effective couplings, histories or environments differ. This motivates a state-sufficiency audit and perturbation-response measurements. It is not unique evidence for process ontology, because sophisticated physiological and dispositional accounts also include such mechanisms.

P5 — Reversibly suppressed activity. A vitrified mammalian embryo may display negligible characteristic metabolic and developmental activity during storage while retaining the ability to resume development after warming. This challenges any simplistic claim that every viable biological individual must be continuously expressing measurable, organism-level activity at physiological rates.

Against an additional product. One can also hypothesize that organized physiological activity *produces* a further entity or causally independent property called life. But such a hypothesis needs independent explanatory work: interventions that remove perfusion, disrupt transport, damage interfaces or restore activity already act through materially specified processes. We have no demonstrated additional variable whose manipulation, independently of those realized processes, explains whether the characteristic living activity

occurs. Therefore **the parsimonious account identifies the actual living process with the physical enactment itself** rather than multiplying causal entities. This is an inference to explanatory economy, **not** a metaphysical proof that dependent emergent properties are impossible; if a distinct property is merely a shorthand for this realized organization, it is compatible with the present account.

These observations support a **process-centered explanatory priority**, not a deductive exclusion of every nonprocess view. Static material inventory is the weakest candidate. A biologically grounded property or capacity account is a much stronger competitor, and can accommodate all five observations when carefully specified. Our question is instead what such a capacity *is a capacity to do*, and which actual physical events realize it.

2.2 The strongest competitor: life as a disposition

The sophisticated dispositional view attributes livingness to a material system's **capacity to sustain or resume its characteristic activities**, even where these are not continuously manifest. Such capacities are physically grounded; they are not immaterial vital forces. The relation between an unmanifested capacity and an actual manifestation is a long-established issue in the metaphysics of dispositions (Mumford, 1998/2003; Bird, 2007). This paper does not originate the distinction.

An account of *actual biological functioning* must nevertheless specify what the system **is doing**, rather than only what it might later do. Actual metabolism, selective transport, repair and regulated activity are not the same events as preserving the capacity for their later expression. Conversely, the assertion that *being alive* demands visibly normal physiological activity at every instant fails to describe deep metabolic suppression and cryopreservation adequately.

Our position is explicit: the *actual living process* is physically enacted relational activity; *biological viability* is the materially grounded, condition-indexed capacity for that process to be sustained or resumed. The distinction concerns enactment and its preserved enabling conditions, not two substances or two mutually exclusive theories. It does not, on its own, supply a universal binary alive/dead classifier.

The direct predecessors include Keilin (1959), Clegg (2001), Neuman (2006) and Lemke (2023) on cryptobiosis, reversible metabolic suppression and suspended life. The relation between activity and reactivation competence has therefore already been discussed. Our use is a **scale-explicit application and explanatory synthesis** focused on mammalian physiological attribution, not a philosophical first discovery.

2.3 The river channel and vitrified embryo

A river may run dry while a physically structured channel remains. Its gradient, geometry and surrounding constraints can support future flow once suitable water supply returns. **The former flow event is not preserved as a continuing flow**; the physical conditions enabling a later flow may be preserved. A channel alone is not sufficient, and renewed water flow need not reproduce an identical microtrajectory.

For a vitrified mammalian embryo, the corresponding judgment is **not optional**. At the level of ordinary developmental physiology, the embryo is **not continuously enacting its characteristic active metabolic and developmental processes during deep cryogenic storage**. It may nonetheless remain a **viably preserved embryo** whose cellular and molecular organization can support renewed development after suitable warming and culture. A clinical classification that calls the embryo *living and preserved* refers to this viability; it should not be taken as evidence that normal active self-maintenance continues at physiological rates. Nor does greatly suppressed metabolic activity establish literal absolute zero biochemical motion or imply that the embryo is dead. This is the substantive distinction; we do not invent a new compulsory clinical category.

The cryptobiosis literature distinguishes negligible activity from death, and sometimes describes states that are neither normally active nor irreversibly dead (Keilin, 1959; Clegg, 2001). Neuman (2006) interprets recovery as biological bootstrapping of organized activity. Lemke (2023) applies suspended-life analysis to technological cryopreservation. **Natural cryptobiosis and artificial embryo vitrification are not identical molecular mechanisms:** they serve as prior conceptual comparisons for what can remain physically intact while ordinary activity is largely arrested. ASRM clinical guidance documents post-warming embryo survival and resumed development (ASRM and SRBT Practice Committees, 2021).

A reversibly arrested heart is a different limit: loss of effective circulation may coexist with many still-active cellular processes. Reversible cardiac arrest is not equivalent to medically determined death. Whether numerical identity persists through interruption is a separate question not settled by the activity–viability distinction.

3. Physical realization and mathematical representation

3.1 States, relations and their joint evolution

Let $q(t)$ denote a hypothetical sufficiently complete physical description of the system. Its existence as a conceptual reference does **not** imply that it can be measured exhaustively in a mammal. Declare a focal biological scale I and an abstraction map:

$$z_I(t) = \Pi_I(q(t)) = (X_I(t), C_I(t)).$$

At a convenient finite resolution, $X_I(t)$ may be a matrix whose rows index cells or compartments, and whose columns contain physical state observables such as relevant concentrations, electrical or mechanical variables, and metabolic states. Because cells may divide, die, move or be replaced, the index set and number of rows need not remain fixed: $X_I(t) \in \mathbb{R}^{N_I(t) \times d_I}$ is one example; variable-node graphs, compartment fields or population distributions can be preferable.

$C_I(t)$ represents **effective causal relations** relevant to that resolution: selectively permeable interfaces, signaling and mechanical couplings, transport capacities, feedback sensitivities or material organization that governs how future changes occur. It is not a physically separate stuff. **The causal couplings are physically real dependencies:** membrane transport, geometry, protein-mediated regulation and mechanical contacts have material mechanisms and intervention consequences. What is model-relative is **which physical variables are encoded as a component state versus an effective relation at a chosen resolution**, not whether the relation exists. Both must be linked to measurements or supported mechanisms. Physical couplings can change rapidly; no universal fast–slow assumption is imposed.

A schematic coupled update is:

$$\begin{aligned} X_I(t + \Delta t) &= \mathcal{F}_I(X_I(t), C_I(t), e_I(t), h_I(t), \xi_t), \\ C_I(t + \Delta t) &= \mathcal{G}_I(C_I(t), X_I(t), e_I(t), h_I(t), \zeta_t). \end{aligned}$$

Here e_I denotes physical inputs and support, h_I relevant history not adequately encoded at that resolution, and ξ_t, ζ_t appropriate uncertainty terms. This is an **abstract representational template**, not an independent biological law. Without constraints on measurement, conservation, interventions, kinetics and error, it has no specific predictive content. Full physiological reconstructions would require many equations, multiscale transport, thermodynamics, mechanical and biochemical dynamics.

The central constitutive claim is not that any system satisfying such equations is alive. It is that a known mammalian living process is **the physical realization represented, imperfectly, by this form**, rather than an extra object produced by solving the equations.

3.2 What self-maintenance commits us to

For a declared mammalian system, some of the conditions enabling characteristic organized activity are at least partly sustained, repaired or regenerated by activities those conditions themselves enable. At the level of an experimentally identified coupling c_j , a local descriptive balance might be written:

$$\Delta c_j = P_j(X, C, e) - D_j(X, C, e),$$

where P_j represents measured sources or repair processes and D_j measured loss or deterioration over an explicit interval. This notation is **not** a theorem of organizational closure, nor does it require every relation to degrade rapidly or participate in a single strongly connected dependency graph. External supplies may be necessary. The proposed causal discipline is to identify an enabling relation and test, under controlled background support, whether suppressing its supporting biological activity changes its maintenance or recovery.

The physiological notion of self-maintenance refers to the **organization's participation in sustaining its own enabling conditions**, not to complete independence from the environment. A mammal constantly exchanges matter and energy, and externally supported organs can maintain selected living processes without being independent organisms.

This commitment has well-established antecedents in autopoiesis, constraint closure and Rosen's metabolism–repair framework. Its role here is to make the identity thesis empirically accountable rather than tautologically true by label alone.

3.3 When the state is not sufficient

If a chosen observable state X_I and recorded environment are insufficient to predict later response, a model may lack relevant microstates, effective relations or history. Changing C_I is one possible representation of additional information; it is not automatically the uniquely correct explanation. Perturbation-response tests—transport selectivity, stimulus-to-force sensitivity, metabolic challenge, restoration after load—can help localize the missing physical cause.

For a physical transition Φ and macrorepresentation Π_I , exact agreement with a closed macro transition Ψ_I would require:

$$\Pi_I(\Phi_{\Delta t}(q, e)) = \Psi_{I, \Delta t}(\Pi_I(q), e_I).$$

This is an idealized causal-abstraction consistency criterion and is not new (Rubenstein et al., 2017; Hoel & Levin, 2020). Empirical use requires a **prespecified approximate or probabilistic version** indexed to measurements, intervention classes, time horizon, tolerances and uncertainty. Two distinct microscopic configurations can share an observed label and then diverge later; this shows insufficiency of the label, not a violation of physical dynamics.

The state–relation scheme thus suggests how to ask what measurements are sufficient for a particular physiological prediction. It does not grant universal sufficiency to a compact matrix.

3.4 Actual activity and protocol-indexed reactivation

The contrast in §2 can be expressed without equating all life to nonzero instantaneous change in a coarse state variable. Let $\mathcal{A}_I$ denote a **study-defined active physiological regime** at scale I , characterised by

independently measurable metabolic or transport throughput, regulated exchange and support of characteristic biological functions over a suitable time window. A near-stationary macroscopic z_I can still represent **intense ongoing flux**; therefore $z_I(t + \Delta t) \neq z_I(t)$ is **not** a criterion of living activity.

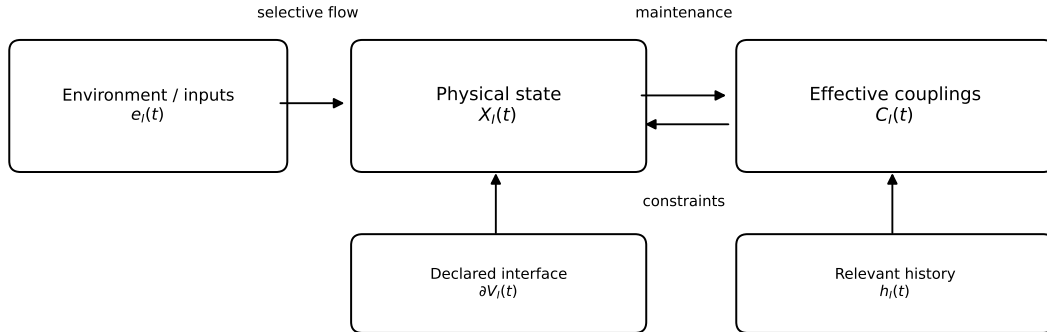
Let U be an explicitly admissible class of physiological supports or restorative interventions, T a finite reactivation horizon, and W an interval over which characteristic activity must be sustained. A **protocol-indexed recoverable set** can be written schematically:

$$\mathcal{R}_I^{U,T,W} = \{z_0 : \exists u \in U, \exists t^* \leq T, z(t^*) \in \mathcal{A}_I, z(t) \in \mathcal{A}_I \forall t \in [t^*, t^* + W]\}.$$

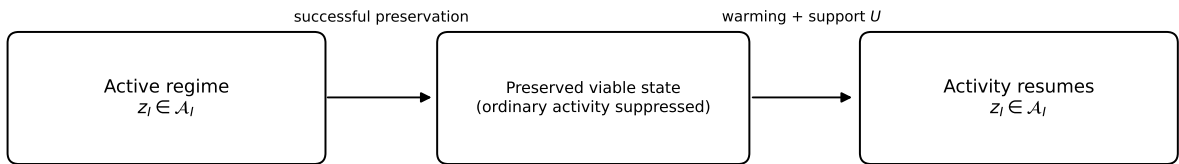
This set is neither a universal classifier of biological life nor an assertion that molecular changes truly cease during freezing. At a coarse, measured embryo-scale resolution, some state changes may be extremely small during storage; rewarming changes environmental input and enables renewed dynamics. A preserved embryo can be **outside the normal active developmental regime while remaining inside an appropriate protocol-indexed recoverable set**. Such terms require specified environmental support, sufficient state measurements and experimentally justified success thresholds.

This resembles a finite-horizon **capture/reachability basin** in mathematical viability theory (Aubin, 1991; Aubin & Haddad, 2002), not necessarily a classical **viability kernel**, which is concerned with maintaining trajectories inside a prescribed constraint set. The construction clarifies the two distinct claims in §2 without deriving numerical identity across interruptions or clinical rules for determining death. This figure illustrates physical realization, history, selective exchange and the separation of active execution from retained recoverability (Figure 1).

A. Physically enacted state-relation dynamics



B. Retained viability is not ongoing physiological execution



Schematic only; not a universal life classifier or a validated quantitative physiological model.

Figure 1: Conceptual scheme of bounded relational dynamics and suspended recoverability. (A) Environmental inputs, measured physical state, effective couplings, history and a declared selective interface are distinguished at a chosen biological resolution. (B) A preserved viable configuration may retain the conditions for renewed activity following appropriate support; the ongoing active process is not stored as an event. The diagram is an explanatory abstraction, not a universally valid life classifier or a fitted mammalian model.

4. Boundary, interface and physical exchange

To say that the system adjusts or maintains **itself** in response to an **environment**, one must specify the focal causal unit. A biological boundary in this explanatory sense is not just a drawn geometric line; it comprises the empirically discriminable relations separating a focal organization from relevant external states and inputs. A physical interface is a selective pathway through which particular matter, energy, mechanical influence or signal can cross.

This specification has **logical**, not developmental or evolutionary, priority for attributing self-maintenance or adaptation: an attributed “self” must have a defined referent. **The underlying biological processes and interfaces are real whether or not an investigator describes them.** Declaring a scale is an epistemic selection among physically instantiated and often nested or overlapping causal organisations, not an act that brings a living process into existence. For a selected scale, a candidate boundary must be justified by measurable selective exchange and relevant reciprocal maintenance or integration; it cannot be assigned arbitrarily, and need not correspond to a unique rigid membrane or a mathematically complete closed loop. In physiology, the boundary is commonly produced, sustained and altered by the very activity it helps regulate. This is reciprocal dependence, not a chronological argument in which a finished wall must exist first.

One may represent cross-boundary graph links at time t by

$$\partial V_I(t) = \{(i, j) : i \in V_I(t), j \notin V_I(t)\}.$$

But a graph cut alone cannot characterize physiological selectivity. A convincing boundary claim names the route, cargo/signal, transport or regulatory conditions, and consequences of targeted intervention. Closing every route would generally destroy the organism’s ability to obtain resources; a living mammalian boundary is **selectively permeable**.

The body outline, cellular membranes, vascular endothelium, immune interface and intestinal lumen do not define the same causal “inside” for all questions. Host–microbiota systems particularly expose this dependence on the declared question. Previous work on closure-defined biological boundaries and immunological individuation already treats many of these issues (Montévil & Mossio, 2015; Pradeu, 2012; Gilbert et al., 2012). Other direct formal comparators are the information-theoretic individuality approach of Krakauer et al. (2020) and the Markov-blanket autonomy analysis of Kirchhoff et al. (2018). These alternative boundary formalisms do not automatically select the same physical interface or biological individual.

5. Two mammalian physiological illustrations

5.1 Intestinal selective barrier

The intestinal lumen lies within the organism’s external silhouette yet remains outside protected internal compartments for many exchange relations. An inner colonic mucus layer can restrict bacterial contact (Johansson et al., 2008), and epithelial junctions have experimentally distinguishable **pore** and **leak** pathways with different selectivities and regulators (Horowitz et al., 2023). These are not interchangeable with barrier defects caused by epithelial injury.

In a limited model, X_I may contain cellular energy, ion and inflammatory state, whereas C_I may represent route-specific conductance, mucus arrangement and effective repair/transport couplings. Their separation is operational rather than metaphysical: epithelial activities help sustain interfaces, and interface selectivity helps determine the exposure conditions in which that activity occurs. Persistent injury can initiate cycles of abnormal exchange, inflammation and impaired repair.

This is a concrete picture of selective exchange and reciprocal maintenance. However, **strong modern**

mucosal physiology already models the pathway-specific distinctions and feedback. Merely rewriting them as a graph does not yield a novel prediction.

5.2 Skeletal-muscle adaptation and retained history

Exercise acutely modifies force generation, blood flow, energy demand, signaling and metabolites; repeated training can modify lasting structures and effective responses. At a chosen resolution, this permits a useful distinction between a transient component-state change and a change in later stimulus–response coupling. Mechanisms and time courses are extensively documented in established exercise physiology (Egan & Sharples, 2023).

In a direct human loading–unloading–reloading study, Seaborne et al. (2018) reported persistent DNA methylation patterns and altered responses even when muscle mass had returned toward baseline. These results show why one coarse current variable cannot stand in for a mechanistically adequate state. But the result itself **predates this manuscript** and supports existing muscle-memory theory. It is not a differential prediction uniquely implied by the present notation.

Both case studies anchor the physical interpretation of X , C , boundaries, maintenance and history without pretending that the symbolic abstraction has reconstructed an organism.

5.3 Worked operational audit: human resistance training

Focal unit: adult skeletal muscle, with neural, vascular, endocrine and mechanical inputs distinguished from its local state.

Measured state (X): muscle mass, maximal torque, measured cellular and metabolic variables, and DNA methylation/expression where available.

Candidate coupling (C): a standardized input–output function mapping load, context and initial state into later force or transcriptional response. Methylation is a measurable state, **not automatically a separate causal relation**.

Perturbation: initial loading, cessation/unloading and reloading at documented doses, with time, history, age, nutrition and other exposures recorded.

Strong baseline: published history-aware exercise physiology and muscle-memory theory, including Seaborne et al. (2018) and Egan and Sharples (2023), rather than an impoverished model that predicts from mass alone. Seaborne et al. used approximately seven weeks each of loading, unloading and reloading, with molecular measurements in a small cohort. We have not analyzed their participant-level data.

Success criterion: before seeing validation results, specify standardized load-to-functional-gain and molecular-response endpoints, a future observation window, independent physiological coupling measurements and an acceptable prediction-error improvement over the strong baseline on held-out interventions. Meaningful added utility requires causal localisation or generalisable prediction not already achieved by that baseline.

Failure criterion: no independently verifiable improvement, attribution to C that vanishes when omitted state or history is measured, or no different intervention decision. Existing literature supports the physiological interpretation, not a new superiority result from this manuscript.

6. Nested livingness and organismal individuality

Mammalian cells maintain local living organization. A perfused excised heart can retain living tissue and selected integrated organ functions, although it does not thereby constitute a self-sufficient mammalian organism. Conversely, irreversible loss of whole-organism functioning does not entail instantaneous death

of every component. Thus “this tissue is biologically active or viable” and “this whole animal remains alive” concern **different referents**.

The present paper allows attribution of actual living processes at several declared scales. This selection **tracks physically supported nested processes; it does not create them by linguistic convention**. It does not define a new universal binary life predicate, assert that every living organ is an independent organism, or conclude that a specific individual’s persistence can be inferred from an isolated viable cell. Cellular, organ and whole-animal descriptions differ in relevant exchanges, control and dependence on host or external life support (Bich, 2024; Wilmsen & Kost, 2025).

Organizational invariance at a sufficiently general level is compatible with change in concrete couplings, tissue composition or physiological gains. Consequently, our evolving $C_I(t)$ does **not**, by itself, refute autopoiesis by showing that a particular organism’s organization need not remain invariant at its own level of description.

7. Close predecessors and bounded contribution

Constitutive process ontology. The physical process is central in Dupré and Nicholson (2018), Nicholson (2018), DiFrisco (2018) and autopoiesis (Maturana & Varela, 1980). That living activities are materially realized processes is not a novel discovery of this paper.

Organization, regulation and variation. Montévil and Mossio (2015), Moreno and Mossio (2015) and Mossio, Montévil and Longo (2016, *Organization*) characterize self-maintaining constraints. Di Paolo (2005) develops adaptivity; Bich et al. (2016) examine biological regulation. Importantly, Montévil, Mossio, Pocheville and Longo (2016, *Variation*) **specifically discuss functional variation with closure preserved across changes of organizational regime**. The separate *Variation* paper supplies the most directly relevant treatment of the interplay between changing biological organization and closure; the *Organization* paper formulates the wider organizational principle. Our evolving effective coupling variable is not a novel discovery of adaptive organization.

Relational, chemical and boundary accounts. Rosen (1991) gives a direct relational metabolism–repair predecessor. Dittrich and Speroni di Fenizio (2007) mathematically characterize chemical organizations. Pradeu (2012), Bich (2024), Wilmsen and Kost (2025), Krakauer et al. (2020) and Kirchhoff et al. (2018) supply distinct approaches to biological boundaries or individuality. The declared-scale boundary used here is a disciplined explanatory choice, not a universally new criterion.

Lineage requirements and local livingness. Ruiz-Mirazo, Peretó and Moreno (2004) propose a universal life definition that includes autonomous organization and an open-ended evolutionary context. Our analysis instead attributes processes at specified mammalian cell, organ and organism scales; neither infertility nor lack of autonomous reproduction excludes living cellular processes. These are different explanatory questions rather than a claimed refutation of evolutionary approaches.

Suspended states and dispositions. Keilin (1959), Clegg (2001), Neuman (2006) and Lemke (2023) already develop accounts of cryptobiosis, preserved organization, reactivation or technologically suspended life. Mumford (1998/2003) and Bird (2007) discuss the metaphysics of dispositions. Their precedents prevent attributing original discovery to the general activity/capacity distinction.

What this paper can legitimately offer. This manuscript proposes a **bounded integration**, consisting of: **(i)** a comparative argument for identifying the *actual living process* with physically enacted relational dynamics while treating viability as a real, physically grounded reactivation capacity; **(ii)** a scale-explicit application to vitrified mammalian embryos and reversible physiological interruption that keeps *actual activity*, *viability*, and the separate issue of *numerical identity* distinct; and **(iii)** methodological discipline for identifying a focal physiological scale, measuring states and effective couplings, specifying perturbations and history, and assessing models against strong existing baselines. All three have significant antecedents;

their value is chiefly explanatory clarification and a usable arrangement, **not demonstrated unique empirical prediction, formal theorem, novel universal classification, or priority over the closest earlier theories.**

8. Implications, tests and limits

The framework directs attention to processes that generate and sustain a measurable physiological regime, rather than treating normal measurements at a single instant as an adequate account of its future. An empirical application should predeclare: a focal causal unit and boundary, relevant observable X , physically supportable couplings C , inputs and history, the perturbation family, and quantitative success or failure criteria. The result must be compared to the best available physiological model with its full set of relevant variables.

The framework does not entail a single universal self-maintenance rate, recovery time or threshold. In a nonlinear system, **a brief state perturbation under unchanged parameters can move a trajectory into another basin of attraction**, yielding a lasting outcome without a parameter update. It is therefore incorrect to assert that durable effects of an intervention necessarily require changing C . Whether long-term modulation occurs through X , an effective C , or both must be determined at a specified modeling resolution and through causal study.

There are potential research programmes, separate from this paper: building physiological capacity during development; measuring loss of recovery speed or increasing effort required to regain a function; and investigating systemic circulating-environment interventions. These applications can motivate hypotheses about healthy future possibilities, but no extension of healthy lifespan, effective plasma treatment or distinct empirical forecast follows from the present ontology alone. Their effectiveness and novelty must be assessed in independently designed studies.

The suspended-embryo case further prevents a simplistic equation of active metabolism and biological viability at every instant. In deep storage, the embryo does **not** enact its normal embryo-scale metabolic and developmental activity, while its physically preserved reactivation competence can remain. This is an explicit, process-level assertion, not a claim that the embryo has died. Physical organization can retain the conditions for resumed dynamics even when characteristic activity is suppressed. At the same time, the account cannot infer from such preservation a complete answer to numerical identity through interruption. Those issues belong to a different analysis.

9. Conclusion

For a known living mammalian system, the **actual living process** is the physically realized, bounded and self-maintaining relational activity of its changing components. This is a constitutive proposal about what that process consists in, not a statement that physical activity produces an additional substance named life. Material components can be renewed, and effective physiological relations can change, while a larger organized process continues. Such activity and its substrate are distinguished: a temporarily interrupted process need not be literally stored as an ongoing event, while its enabling material conditions may remain sufficiently intact for reactivation.

The explanatory strength of the account lies in its insistence on physically specified processes, interfaces, reciprocal maintenance and declared biological scales. Its limits are equally important: retained viability is a real physical disposition; local tissue activity is not whole-organism independence; an abstract matrix is not a living system; and current physiological cases do not demonstrate superiority over existing mechanistic theory. The proposal is thus an **integrative constitutive account with explicit empirical discipline**, not a new universal law of life.

Declaration of AI assistance

Generative AI language-model tools assisted with literature discovery, manuscript drafting, language editing and critical review. The conceptual decisions and responsibility for the manuscript, including checking references and resolving errors before public release, rest with the author. No AI system is listed as an author.

References

- American Society for Reproductive Medicine and Society of Reproductive Biologists and Technologists, Practice Committees. (2021). A review of best practices of rapid-cooling vitrification for oocytes and embryos: a committee opinion. *Fertility and Sterility*, 115, 305–310. ASRM guideline.
- Aubin, J.-P. (1991). *Viability Theory*. Birkhäuser.
- Aubin, J.-P., & Haddad, G. (2002). Impulse capture basins of sets under impulse control systems. *Journal of Mathematical Analysis and Applications*, 275(2), 676–692. doi:10.1016/S0022-247X(02)00377-3.
- Bich, L., Mossio, M., Ruiz-Mirazo, K., & Moreno, A. (2016). Biological regulation: Controlling the system from within. *Biology & Philosophy*, 31, 237–265. doi:10.1007/s10539-015-9497-8.
- Bich, L. (2024). Integrating multicellular systems: Physiological control and degrees of biological individuality. *Acta Biotheoretica*, 72, 1. doi:10.1007/s10441-023-09476-4.
- Bird, A. (2007). *Nature's Metaphysics: Laws and Properties*. Oxford University Press. DOI.
- Clegg, J. S. (2001). Cryptobiosis—a peculiar state of biological organization. *Comparative Biochemistry and Physiology B*, 128, 613–624. doi:10.1016/S1096-4959(01)00300-1.
- Di Paolo, E. A. (2005). Autopoiesis, adaptivity, teleology, agency. *Phenomenology and the Cognitive Sciences*, 4, 429–452. doi:10.1007/s11097-005-9002-y.
- DiFrisco, J. (2018). Biological processes: Criteria of identity and persistence. In *Everything Flows*. Oxford University Press. doi:10.1093/oso/9780198779636.003.0004.
- Dittrich, P., & Speroni di Fenizio, P. (2007). Chemical organisation theory. *Bulletin of Mathematical Biology*, 69, 1199–1231. doi:10.1007/s11538-006-9130-8.
- Dupré, J., & Nicholson, D. J. (2018). A manifesto for a processual philosophy of biology. In *Everything Flows*. Oxford University Press. doi:10.1093/oso/9780198779636.003.0001.
- Egan, B., & Sharples, A. P. (2023). Molecular responses to acute exercise and their relevance for adaptations in skeletal muscle to exercise training. *Physiological Reviews*, 103, 2057–2170. doi:10.1152/physrev.00054.2021.
- Gilbert, S. F., Sapp, J., & Tauber, A. I. (2012). A symbiotic view of life: We have never been individuals. *Quarterly Review of Biology*, 87, 325–341. doi:10.1086/668166.
- Hoel, E., & Levin, M. (2020). Emergence of informative higher scales in biological systems: A computational toolkit for optimal prediction and control. *Communicative & Integrative Biology*. doi:10.1080/19420889.2020.1802914.
- Horowitz, A., Chanez-Paredes, S. D., Haest, X., & Turner, J. R. (2023). Paracellular permeability and tight junction regulation in gut health and disease. *Nature Reviews Gastroenterology & Hepatology*, 20, 417–432. doi:10.1038/s41575-023-00766-3.
- Johansson, M. E. V., Phillipson, M., Petersson, J., et al. (2008). The inner of the two Muc2 mucin-dependent mucus layers in colon is devoid of bacteria. *PNAS*, 105, 15064–15069. doi:10.1073/pnas.0803124105.
- Keilin, D. (1959). The problem of anabiosis or latent life: history and current concept. *Proceedings of the Royal Society B*, 150, 149–191. doi:10.1098/rspb.1959.0013.
- Kirchhoff, M. D., Parr, T., Palacios, E., Friston, K., & Kiverstein, J. (2018). The Markov blankets of life: Autonomy, active inference and the free energy principle. *Journal of the Royal Society Interface*, 15, 20170792. doi:10.1098/rsif.2017.0792.
- Krakauer, D., Bertschinger, N., Olbrich, E., Flack, J. C., & Ay, N. (2020). The information theory of individuality. *Theory in Biosciences*, 139, 209–223. doi:10.1007/s12064-020-00313-7.
- Lemke, T. (2023; online 2022). Conceptualising suspended life: From latency to liminality. *Theory, Culture & Society*, 40(6), 69–86. doi:10.1177/02632764221113737.
- Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and Cognition: The Realization of the Living*. D. Reidel.
- Montévil, M., & Mossio, M. (2015). Biological organisation as closure of constraints. *Journal of Theoretical Biology*, 372, 179–191. doi:10.1016/j.jtbi.2015.02.029.
- Montévil, M., Mossio, M., Pocheville, A., & Longo, G. (2016). Theoretical principles for biology: Variation. *Progress in Biophysics and Molecular Biology*, 122, 36–50. doi:10.1016/j.pbiomolbio.2016.08.005.

- Moreno, A., & Mossio, M. (2015). *Biological Autonomy*. Springer. doi:10.1007/978-94-017-9837-2.
- Mossio, M., Montévil, M., & Longo, G. (2016). Theoretical principles for biology: Organization. *Progress in Biophysics and Molecular Biology*, 122, 24–35. doi:10.1016/j.pbiomolbio.2016.07.005.
- Mumford, S. (1998; Oxford online 2003). *Dispositions*. Oxford University Press. DOI.
- Neuman, Y. (2006). Cryptobiosis: A new theoretical perspective. *Progress in Biophysics and Molecular Biology*, 92, 258–267. doi:10.1016/j.pbiomolbio.2005.11.001.
- Nicholson, D. J. (2018). Reconceptualizing the organism: From complex machine to flowing stream. In *Everything Flows*. Oxford University Press. doi:10.1093/oso/9780198779636.003.0007.
- Pradeu, T. (2012). *The Limits of the Self: Immunology and Biological Identity*. Oxford University Press.
- Rosen, R. (1991). *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*. Columbia University Press.
- Rubenstein, P. K., et al. (2017). Causal consistency of structural equation models. *UAI 2017*. PMLR version.
- Ruiz-Mirazo, K., Peretó, J., & Moreno, A. (2004). A universal definition of life: Autonomy and open-ended evolution. *Origins of Life and Evolution of the Biosphere*, 34, 323–346. doi:10.1023/B:ORIG.0000016440.53346.dc.
- Seaborne, R. A., et al. (2018). Human skeletal muscle possesses an epigenetic memory of hypertrophy. *Scientific Reports*, 8, 1898. doi:10.1038/s41598-018-20287-3.
- Wilmsen, S., & Kost, C. (2025). Defining organismality. *Biological Theory*, 20, 54–70. doi:10.1007/s13752-024-00486-0.