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Sensing, Feeling, Affect, and the Origins of Cognition in Biological Systems

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Abstract: Cognition is often modeled in terms of abstract reasoning and neural computation, yet biological evidence shows that the roots of cognition lie in far more fundamental processes. This article develops a theory of cognition grounded in sensing, feeling, and affect—capacities that precede nervous systems and are present even in the simplest forms of life. Drawing on **the** info-computational framework, we argue that cognition and proto-subjectivity co-emerge in biological systems: the embodied evaluation of internal and external conditions in terms of valence and the capacity to act accordingly are mutually constitutive dynamics. This concept reframes cognition not as disembodied information processing, but as embodied, value-sensitive information dynamic**s**—self-regulating engagements with the environment, continuous across biological scales. In this view, information is physically instantiated, and computation is the dynamic, self-modifying process by which organisms regulate and reorganize themselves. Cognition thus emerges from the dynamic coupling of sensing, internal evaluation, and adaptive morphological activity. Grounded in findings from developmental biology, bioelectric signaling, morphological computation, and basal cognition, this account situates intelligence as an affectively regulated process intrinsic to life itself. While focused on biological systems, this framework may also offer conceptual insights for the development of more adaptive and embodied forms of artificial intelligence. Future experimental work in synthetic or minimal biological systems may help to operationalize and test the proposed mechanisms of proto-subjectivity and affective regulation.

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1. Defining Sensing, Feeling, Affect, and Emotion

To start with, we clarify what is meant by sensing, *feeling*, *affect*, and *emotion*, as these terms are often conflated or inconsistently used across disciplines. These phenomena represent a functional succession in biological systems, from initial environmental detection to increasingly complex forms of evaluation and regulation.

Sensing refers to the system's basic capacity to detect stimuli/inputs from the external environment and from internal bodily milieu. It provides the data/information for subsequent layers of cognitive processing/appraisal.

Feeling is understood as the most basic form of valence-based appraisal in a biological system. It refers to the system's capacity to register internal or environmental conditions as more or less favorable, and to use this information to guide regulation and action. Feeling is the biological encoding of value—an evaluative signal that supports adaptive behavior. It triggers phenomena such as chemotaxis, homeostatic feedback, and cellular stress responses.

Affect refers to the dynamic regulation of internal states in response to such valence appraisals. It encompasses the continuous process of modulating metabolic, electrical, or morphological conditions in ways that maintain or restore preferred states. Affect is processual—it describes the flow and transformation of value-based information over time within the system.

Emotion emerges in more complex organisms with nervous systems. It represents a higher-order patterning of affective responses often involving coordinated changes in physiology, behavior,

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and conscious experience. While emotion is layered upon feeling and affect, it is not synonymous with them.

In biological and info-computational context, feeling and affect are foundational components of cognition. They precede symbolic reasoning and neural representation and are embedded in the physical and informational dynamics of life from its simplest forms onward.

2. Sensing and Feeling First

Having clarified the distinctions between sensing, feeling, affect, and emotion, we now turn to the central question: why begin with sensing and feeling as the foundation of cognition?

Much of cognitive science and AI begins with assumptions about cognition drawn from adult human minds: linguistic capacity, abstract reasoning, and symbol manipulation. But these capacities sit atop a much older and deeper foundation: the capacity to sense, appraise, regulate, and adapt. This article argues that feeling, understood as the affective modulation of internal states in response to environmental (internal/external) signals acquired by sensing, is the primary feature of cognition and its biological origin.

Feeling results from a more basic process of valence-based appraisal: a system's capacity to differentiate beneficial from harmful conditions, to prefer some states over others, and to act accordingly. It is the biological encoding of value that drives homeostatic regulation, chemotactic responses, and cellular stress adaptation. Feeling, in this evolutionary sense, is not a byproduct of cognition; it is its foundation.

Whereas sensing provides data from the environment, feeling is the evaluative layer that determines relevance and drives behavior. Sensing without feeling would result in undifferentiated information with no basis for action or prioritization. Feeling, even in its most basic form, equips organisms with a directional orientation toward the world, shaped by internal needs and environmental relevance. This minimal evaluative capacity constitutes a foundational layer of cognition—what may be described as *proto-subjectivity*: the system's ability to relate to its environment through internal norms of viability and regulation (Barandiaran et al., 2009; Dodig-Crnkovic, 2025).

This perspective aligns with insights from Antonio Damasio (1999, 2018), who argues that feelings arise from the internal mapping of bodily states, and with Mark Solms (2021), who, focusing on humans, proposes that affective valence is the most basic form of consciousness—a perspective that may hold relevance across species. Even more fundamentally, affective dynamics exist in non-neural organisms, as shown in basal cognition literature (Lyon et al., 2021), suggesting that feeling precedes nervous systems.

We focus on cognition within the continuity of life, grounding it in real biological systems rather than disembodied abstractions. This approach is informed by the evolutionary perspective advanced in the Extended Evolutionary Synthesis (Laland et al., 2015) and the conceptual frameworks of Denis Noble (2006) and Simona Ginsburg and Eva Jablonka (2019), which highlight cognition as an intrinsic feature emerging early in life's history. We build on cellular-molecular mechanisms in epigenetic evolutionary biology (Torday et al., 2020), with a focus on cognition-based evolution (Torday & Miller, 2020). We also draw from the pioneering work of Michael Levin, who demonstrates bioelectrical and morphogenetic signaling as foundational to cellular and tissue-level cognition (Levin, 2019, 2022), and from Witzany's insights on biological communication and signaling processes as essential for life and cognition (Witzany, 2012). These biological insights are continuous with theories of embodied cognition (Varela et al., 1991), enactivism (Thompson, 2007), developmental systems theory (Oyama, 2000), and basal cognition (Lyon, 2006), together situating cognition as a multi-level, embodied, and evolutionary process.

This approach conceptualizes cognition not as manipulation of symbols, but as the lived regulation of life processes within the info-computational framework (Dodig-Crnkovic, 2022), where physical structures and informational flows are co-constituted.

We expand on this foundational perspective in the following section by developing the concept of proto-subjectivity, grounding it in empirical observations and theoretical frameworks across biology and cognitive science.

2.1. Proto-Subjectivity: The Biological Basis for Perspective and Value

While much of cognitive science begins with consciousness or abstract reasoning, we argue that a minimal but meaningful form of subjectivity—proto-subjectivity—is intrinsically linked with the emergence of cognition itself. Rather than treating proto-subjectivity as a precursor to cognition, we propose that the two are mutually constitutive: proto-subjectivity involves the system's capacity to evaluate conditions relative to its own viability, while cognition encompasses the regulatory, adaptive, and informational processes through which such evaluations are enacted. In biological systems, this interplay gives rise to an embodied orientation toward the world, marked by selective sensitivity, internal normativity, and self-maintaining activity.

This co-emergent relationship is evident even in the simplest organisms, where adaptive behaviors—such as chemotaxis or stress responses—reflect both informational processing and a form of primitive concern for internal states. The system's organization encodes preferences and constraints that guide action, not through conscious intention, but through materially grounded regulation. This is not cognition added to life, but cognition **as** life: an affectively modulated informational process arising in and through biological structure.

To formalize this, we adopt the conceptual framework proposed by Barandiaran et al. (2009), who define minimal agency through four criteria: individuality, normativity, asymmetry, and spatiotemporal cohesion. These criteria are met by many single-celled and multicellular systems through adaptive homeostatic regulation, value-driven signaling, and morphological computation. This reframing also aligns with Ginsburg and Jablonka's (2019) account of minimal consciousness, which places the roots of subjective life in the evaluative dynamics of even simple organisms.

Supporting this is the info-computational framework, which models living systems as self-modifying, morphologically computing agents. These agents continually reconstruct their own internal architecture in response to both environmental input and internal goals, effectively computing their own next state. Within this model, Dodig-Crnkovic (2025) argues for a spectrum-based view of cognition and mind, where mental functions are not exclusive to humans or animals with brains, but extend across life. Her call to de-anthropomorphize the mind provides crucial theoretical support for interpreting even minimal evaluative behavior as cognitive—not metaphorically, but functionally.

We therefore propose that proto-subjectivity is not speculative, but empirically grounded in well-documented regulatory behaviors. It can be identified through a combination of criteria:

Internal state monitoring and homeostatic feedback (e.g., chemotaxis)

Historical sensitivity and memory-like behavior (e.g., path optimization in *Physarum*)

Norm-directed adaptive actions (e.g., regeneration guided by bioelectric fields in planaria)

Goal-relative behavior selection (e.g., avoidance of toxic gradients in bacteria)

These examples reveal a basic organizational stance: the system distinguishes between more and less favorable states and acts accordingly to preserve itself. This is the root of meaning in biological systems—not symbolically represented, but embodied in affectively regulated behavior. This is not to suggest that single cells are conscious in a phenomenological sense. Rather, we argue that cognition begins with and through this co-emergent capacity to care, functionally speaking, about one's internal and relational conditions.

As such, proto-subjectivity provides a biologically grounded starting point for understanding cognition not as abstract problem-solving, but as a lived, affectively modulated regulation of life.

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3. The Basal Roots of Cognition

The fundamental paradigm-shift is the insight that cognition begins not in the neocortex, but in the cell. The cellular basis of cognition has been elaborated in the work of Michael Levin and Pamela Lyon. Levin (2022) demonstrates how bioelectrical signaling across tissues encodes pattern memories, regulates behavior, and mediates goal-directed repair and regeneration. Lyon (2021) introduces the framework of basal cognition, attributing cognitive capacities—such as perception, memory, learning, and decision-making—to non-neural organisms, including single cells, plants, and slime molds.

Basal cognition posits that cognition is coextensive with life (Maturana & Varela, 1980). That is, the defining properties of life—self-maintenance, responsiveness, and adaptivity—are inherently cognitive. A single bacterium detects nutrient gradients, modulates its metabolism, and changes its motility accordingly. This behavior is not just reflexive, but regulated through feedback, signaling cascades, and molecular memory.

Cells in multicellular organisms exhibit remarkable coordination and collective intelligence. Through chemical and bioelectrical signaling, tissues self-organize, repair damage, and regenerate lost structures. Levin's work with planaria shows that amputated worms regenerate correct morphology based on global bioelectric patterns—not genetic instructions alone. These findings suggest that even at the tissue level, information is processed, stored, and deployed in ways that resemble distributed cognition (Levin & Martyniuk, 2018; Levin, 2022). Levin's more recent work (Levin, 2023) further elaborates how bioelectric networks act as a cognitive glue, enabling the scaling of information integration and goal-directed activity from the physiological level to complex behavior and cognition.

These research results challenge the assumption that cognition requires a nervous system. Cognition emerges from the coupling of sensing, feeling, regulation, and morphology, giving systems a perspective, however minimal. Fields et al. (2021) argue that cognition is grounded in bioelectric and morphological computation, enabling cells to act as agents embedded in dynamic fields of constraints and affordances.

4. Toward Morphological and Self-Modifying Intelligence. Computing Beyond Turing

Classical computational models, such as the Universal Turing Machine, fall short in capturing the complexity of biological systems. Organisms are not passive processors of input—they are self-organizing, adaptive, and creative systems. As Hava Siegelmann (2013) notes, adaptation, choice, and learning exceed the bounds of fixed algorithmic computation.

George Kampis (1991) offers a compelling proposal: biological organisms modelled as component-systems—self-referential, self-modifying computers. These systems continually redefine their own hardware and software:

"A component system is a computer which, when executing its operations (software), builds a new hardware.... The hardware defines the software and the software defines new hardware. Then the circle starts again." (Kampis, 1991, p. 223)

Such systems do not merely process information—they at the same time construct and reconstruct their own architectures. This recursive capacity is essential for the open-ended development, creativity, and plasticity of biological life.

Focusing on real-time information-processing aspects, Carl Hewitt's Actor Model describes computation as distributed, concurrent, and context-sensitive message passing in a network of actors. Actors are autonomous entities that process messages, spawn new actors, and evolve behavior through interactions—representing how cells and tissues act in a decentralized, emergent manner. These models break from centralized symbol-processing of the Turing Machine model, and emphasize structural adaptability and concurrency, much like biological systems.

This perspective aligns with an expanded understanding of computation, beyond the classical Turing model. As articulated by Burgin and Dodig-Crnkovic (2015), computation spans a spectrum—from algorithmic and symbolic to interactive, morphological, and natural forms. Their taxonomy clarifies how biological systems exemplify self-modifying and embodied computation, where structure and process co-evolve. Within this framework, living organisms do not merely execute pre-defined algorithms; they compute by physically reorganizing themselves in response to internal and external signals. This broader conception supports the info-computational model adopted here, where cognition unfolds as a recursive interaction of form, information, and affective regulation.

While the primary focus of this article is biological cognition, these insights bear implications for efforts in artificial intelligence. Contemporary AI systems, largely modeled on disembodied symbol processing, could benefit from biologically inspired architectures grounded in affective regulation and morphological adaptability. Although full treatment is beyond the scope of this work, recognizing cognition as an embodied, value-driven process invites future exploration into how artificial systems might incorporate minimal affective dynamics—not to replicate biology, but to broaden conceptual models of adaptive agency.

This provides the basis for info-computationalism (Dodig-Crnkovic, 2012, 2022), which frames cognition as embodied computation unfolding in and through physical structures. It unifies symbolic and sub-symbolic processes under the broader umbrella of morphological computation—the view that form, function, and information co-evolve in physical systems.

Table 1. Types of Computation in Biological Systems.

Computation Type	Definition	Biological Example	Reference Model
Symbolic (Turing)	Rule-based manipulation of discrete symbols	Digital computers, formal logic	Turing machine
Sub-symbolic	Pattern recognition without explicit symbol use	Neural networks, reflex arcs	Connectionist models
Morphological	Computation embedded in physical form and dynamics	Plant growth, slime mold adaptation	Pfeifer & Bongard (2007)
Bioelectric / Self-modifying	Recursive reconfiguration of structure and behavior based on internal feedback	Regenerative repair in planaria, tissue morphogenesis	Kampis (1991), Levin (2023)
Info-computational	Integrated processing of form, information, and value-regulation	All levels of life—cells to cognition	Dodig-Crnkovic (2022, 2025)

5. Information Processing from Sensation to Emotion. The Affective Ladder of Cognition

Evolutionarily, cognition does not arise abruptly with abstract reasoning or conscious thought. It is scaffolded through a layered sequence of biological processes: *sensation*, the detection of environmental or internal stimuli; *feeling*, the appraisal of these stimuli in terms of valence; *affect*, the regulation of internal states in response to such appraisals; and finally, *emotion*, a higher-order patterning of affective responses typically associated with nervous systems. This affective ladder constitutes the deep infrastructure of cognition. Rather than being a product of intelligence, emotion—like the layers beneath it—is part of the dynamic substrate that makes intelligence possible.

Affect in biological systems integrates internal states and environmental signals to maintain coherence and adaptivity. It emerges from earlier layers—sensation and feeling—and supports the organism's ability to prioritize and modulate behavior in real time. From stress responses in single cells to coordinated physiological states in multicellular organisms, affect acts as a regulatory interface: it biases actions, tunes responses, and preserves systemic viability. This evaluative function is present even in simplest life forms, demonstrating that cognition begins not with logic, but with embodied strategies for staying alive.

Every act of sensing in a living system involves more than passive detection—it initiates a cascade of evaluation. To sense is already, in some form, to judge (Damasio, 1999; Lyon et al., 2021). A bacterium swimming toward nutrients is not merely reacting; it is expressing a preference shaped by internal metabolic states and historical feedback (Maturana & Varela, 1980; Fields et al., 2021). This basic form of valenced behavior reflects a proto subjectivity: the system's capacity to relate to the world from its own organizational standpoint (Barandiaran et al., 2009). As these regulatory mechanisms grow in complexity through evolution, they give rise to emotional states in organisms with nervous systems—structured constellations of affect that coordinate physiology, perception, and behavior (Solms, 2021; Friston & Seth, 2016).

As Damasio (1999, 2018), Solms (2021), and Friston & Seth (2016) argue, affective dynamics precede representational cognition and are rooted in the organism's ongoing internal mapping of its own physiological states. These dynamics are not mere responses—they are constitutive of life's organizational logic. In living systems, affect modulates the very processes by which the organism generates and regulates its own future states.

Table 2. The Affective Ladder of Cognition.

Layer	Definition	Examples	Biological Level
Sensing	Detection of internal or external stimuli	Chemoreception, mechanoreception	Single-cell and multicellular
Feeling	Basic valence-based appraisal of stimuli	Chemotaxis toward nutrients, stress-induced gene expression	All living cells
Affect	Regulation of internal state based on value appraisals	Homeostasis, bioelectrical modulation	Tissues, organs
Emotion	Coordinated affective states involving physiological and behavioral change	Fear, pleasure, arousal	Nervous-system-based organisms

Kampis's (1991) model of self-modifying systems supports this view: biological systems recursively construct their own architectures based on internal evaluations. In such systems, affective states guide not just behavior but the reconfiguration of the self. Emotion, then, is not an epiphenomenon of cognition—it is a core mechanism in the self-construction of living intelligence.

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5.1. *Molecules of Emotion in Unicellular Life: The Biochemical Roots of Affect*

The biochemical machinery underlying emotion is not exclusive to multicellular organisms. In fact, what Candace Pert famously termed the "molecules of emotion"—primarily neuropeptides and their receptors—can be found in unicellular organisms, revealing an ancient evolutionary substrate for affective processes. These molecules, once considered unique to the human nervous system, are now known to participate in cell signaling, homeostasis, and adaptive responses in bacteria and other single-celled organisms (Pert, 1997).

This molecular continuity strongly supports the thesis that emotion, in its most basic form, is not a human invention, but a fundamental property of life. Ligand-receptor signaling systems in unicellular organisms serve not only to mediate metabolic regulation but also to guide behavior based on internal states and environmental cues. For example, bacterial chemotaxis—movement toward or away from chemical stimuli—is modulated by receptor activity in ways that mirror preference-based orientation. Pamela Lyon (2015) refers to such mechanisms as evidence for proto-emotional behavior, rooted in the capacity for physiological self-regulation and environmental responsiveness.

These systems reflect a kind of minimal affect: an evaluative dynamic that enables the organism to modulate its activity in ways conducive to survival. In this view, emotion is not a late-emerging psychological category, but a deeply conserved biological function—built from molecular signaling systems that predate neurons, brains, and even multicellularity. This reinforces the article's central claim that feeling is evolutionarily primary, and that the roots of cognition lie in the body's chemical capacity to care about its own conditions.

6. Morphology, Intelligence, and the Info-Computational Synthesis

Intelligence is not localized only in a brain, as often assumed, it is distributed throughout living structure as a network of valenced, goal-directed information-processes. Organisms compute their own preferred future states and behaviors with their form (*morphology*).

Slime molds solve mazes with their tubular networks. Plants adapt root growth to changing gradients. Tissue systems respond to wounds through collective bioelectrical reorganization. In all these cases, the body does not represent the environment—it interacts with it directly through feedback loops embedded in material properties (Levin, 2019; Levin, 2023; Trewavas, 2003). Levin (2023) emphasizes how bioelectric networks serve as a scalable cognitive infrastructure, enabling integration across levels—from cellular physiology to organism-wide coordination—thus implementing a non-neural basis for intelligence.

Robotic models support this view. Pfeifer and Bongard (2007) show that embodied intelligence—where control is shared across morphology and dynamics—outperforms symbolic control systems in adaptability and robustness.

Based on those empirical findings, within the info-computational framework, cognition is described as embodied, morphological computation—not only traditional symbol manipulation, but recursive interaction between structure, information, and environment. This synthesis redefines intelligence in a living organism as a felt, evolving process: embedded, regulated, and continuous. Affective processes—feelings, valences, emotional dynamics—are not external to this computation but constitute integral informational dynamics through which organisms regulate themselves and anticipate change. Living systems compute their own next state through structured, embodied interactions shaped by value and viability.

6.1. *Cognition and Intelligence: Navigating Problem Spaces*

Within this framework, cognition is understood as the embodied, affect-regulated process by which living systems sense, evaluate, and interact with their environments. Intelligence, in turn, refers to the capacity of an organism to solve problems—not within a single fixed domain, but across diverse spaces of constraint and opportunity. Following Michael Levin's work (Levin, 2022), this

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includes morphospace (the space of possible bodily forms), physiological space, behavioral space, and even goal space.

Intelligence, then, is not defined by symbolic reasoning or language, but by the adaptive versatility of cognition: the ability to achieve viable outcomes across shifting conditions, using different strategies. A regenerative organism, for example, may solve the problem of injury by navigating morphospace to reconstruct missing structures—an act of intelligence grounded in bioelectric pattern memory (Levin, 2019). Even single-celled organisms display forms of intelligence when they flexibly adjust behavior to chemical gradients, optimize energy use, or alter internal states to resist stress.

This view aligns with Sloman's (2010) account of cognitive architectures that evolve increasing layers of control and representation, enabling organisms to handle novel, nested, and abstract problems. Intelligence becomes a measure of cognitive generality: not just acting effectively, but reorganizing internal structures or strategies to do so under changing or unfamiliar conditions.

7. Conclusions: Cognition as the Felt Process of Life in the Body of a Cognitive Agent

Cognition is the ongoing, affectively regulated, embodied process by which living systems maintain coherence in a changing world. It does not arise from disembodied algorithms or symbolic logic, but from the recursive organization of life itself—from the capacity to sense, evaluate, and reorganize. We have argued that proto-subjectivity and cognition co-emerge in biological systems as mutually constitutive capacities: the ability to appraise internal and external conditions in terms of viability, and the information-processing dynamics that implement such appraisals through adaptive regulation.

Feeling, understood as a valenced sensitivity to one's own states and surroundings, is not a byproduct of intelligence—it is part of its evolutionary infrastructure. This minimal evaluative stance enables even simple organisms to distinguish between beneficial and harmful conditions and to act accordingly. From bacterial chemotaxis to morphogenetic adaptation in tissues, the capacity to regulate based on internal significance reflects an organizational perspective—a primitive form of "being in relation."

These foundational capacities scaffold increasingly complex regulatory architectures, culminating in what we recognize as emotion, deliberation, and reflective reasoning. Even in humans, these later forms remain rooted in the same dynamics: as Kahneman (2011) notes, "thinking fast"—intuitive and emotionally guided cognition—emerges from deeply embodied processes that long predate symbolic thought.

The info-computational framework offers a unifying model in which cognition is understood as morphological self-computation: an ongoing interaction of structure, information, and environment, modulated by internal evaluative dynamics. In this view, information is embodied—a physically instantiated pattern—and computation is the process by which organisms regulate and transform these patterns in ways that preserve coherence and viability.

Simulation may reproduce surface-level features of cognition, but biological minds are rooted in affective regulation and structural self-modification. To understand cognition in its full scope and continuity, we must begin not with abstract logic or symbolic processing, but with living systems that feel, regulate, and reconstitute themselves in relation to the world.

7.1. Toward Experimental Grounding: Testing Co-Emergent Cognition and Proto-Subjectivity

The conceptual model presented here—where cognition and proto-subjectivity arise together as embodied, valence-sensitive information dynamics—invites empirical exploration. If these capacities are not abstractions but real biological phenomena, then they should be observable, testable, and experimentally tractable even in the simplest living systems.

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One promising direction involves minimal biological agents, such as Physarum polycephalum, which exhibits historical memory, environmental valuation, and adaptive optimization. Experiments that modulate its internal biochemical or electrical states could help determine whether internal valence-like dynamics causally influence behavioral decisions—providing evidence for the co-emergence of regulation and evaluative stance.

A second approach targets synthetic and engineered microbial systems. Using designed gene circuits, researchers can couple internal metabolic markers to chemotactic sensitivity or behavioral outputs. Such systems could test whether biologically meaningful internal states modulate external orientation, indicating a primitive form of embodied appraisal embedded in regulatory computation.

In multicellular contexts, organoids or regenerative model organisms like planaria provide a platform to explore how bioelectric fields and morphological information influence system-level outcomes. Michael Levin's work has shown that altering bioelectrical gradients can change the target morphology of regenerating organisms. Future experiments could examine whether prior perturbation history or systemic coherence modulates these outcomes—revealing a kind of adaptive, memory-based regulation consistent with proto-subjective cognition.

These experimental programs would not only operationalize the concept of proto-subjectivity, but also help specify how cognition is embodied, distributed, and co-evolving with regulation. They offer an opportunity to refine the theory and test its predictions in real biological systems, potentially advancing both theoretical biology and synthetic cognition research.

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