Sensing, Feeling, and Origins of Cognition

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Entry

Sensing, Feeling, and Origins of Cognition

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Definition

Cognition is often modeled in terms of abstract reasoning and neural computation, yet a growing body of theoretical and experimental work suggests that the roots of cognition lie in fundamental embodied regulatory processes. This article presents a theory of cognition grounded in sensing, feeling, and affect—capacities that precede neural systems and are observable in even the simplest living organisms. Based on the info-computational framework, this entry outlines how cognition and proto-subjectivity co-emerge in biological systems. Embodied appraisal—the system's ability to evaluate internal and external conditions in terms of valence (positive/negative; good/bad)—and the capacity to regulate accordingly are described as mutually constitutive processes observable at the cellular level. This concept reframes cognition not as abstract symbolic reasoning but as value-sensitive, embodied information dynamics resulting from self-regulating engagement with the environment that spans scales from unicellular organisms to complex animals. In this context, information is physically instantiated, and computation is the dynamic, self-modifying process by which organisms regulate and organize themselves. Cognition thus emerges from the dynamic coupling of sensing, internal evaluation, and adaptive morphological (material shape-based) activity. Grounded in findings from developmental biology, bioelectric signaling, morphological computation, and basal cognition, this account situates intelligence as an affect-driven regulatory capacity intrinsic to biological life. While focused on biological systems, this framework also offers conceptual insights for developing more adaptive and embodied forms of artificial intelligence. Future experiments with minimal living systems or synthetic agents may help operationalize and test the proposed mechanisms of proto-subjectivity and affect regulation.

Keywords: cognition; sensing; feeling; info-computation; artificial intelligence

Academic Editor: Raffaele Barretta

Received: 27 August 2025
Revised: 23 September 2025
Accepted: 29 September 2025
Published: 8 October 2025

Citation: Dodig-Crnkovic, G. Sensing, Feeling, and Origins of Cognition. *Encyclopedia* **2025**, *5*, 160. https://doi.org/10.3390/encyclopedia5040160

1. Defining Sensing, Feeling, Affect, and Emotion

To start with, we define the terms sensing, feeling, affect, and emotion, which 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 a system's basic capacity to detect stimuli from the external environment or its internal bodily milieu. It provides raw data for subsequent cognitive processes such as appraisal and regulation. Example: A bacterium detects a glucose gradient via membrane receptors.

Feeling is defined as the system's ability to register internal or external conditions as more or less favorable—a basic form of value appraisal. This internal signal serves to guide physiological regulation or adaptive behavior.

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. Example: In nutrient-deprived conditions, bacterial cells exhibit simple preference-based behavior grounded in internal viability. They initiate gene expression changes indicating metabolic "frustration"—a primitive form of feeling.

Affect is the ongoing, dynamic modulation of internal states based on valence appraisals. It encompasses metabolic, electrical, and structural regulation aimed at maintaining or restoring system viability. Affect is processual—it describes the flow and transformation of value-based information over time within the system. Example: Homeostatic adaptation in response to heat or osmotic stress.

Emotion is a more complex, structured pattern of affective responses typically seen in organisms with nervous systems. It often involves coordination of physiology, behavior, and subjective experience. It often involves coordination of physiology, behavior, and subjective experience. Emotion is dependent on, but not reducible to, feeling and affect. It arises from integrated processing across neural, endocrine, and behavioral systems.

Example: A rodent freezing in fear involves coordinated neural, hormonal, and muscular responses.

In biological and info-computational context, feeling and affect are foundational components of cognition. They precede symbolic reasoning and neural representation and are embodied 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?

Traditional models of cognition in cognitive science and AI often begin with capacities found in adult human minds—such as language, symbolic reasoning, and abstract problem-solving. However, these high-level capacities rest upon an evolutionarily older foundation: the organism's capacity to sense, appraise, regulate, and adapt. In this framework, feeling—understood as the valence-based modulation of internal states in response to sensed conditions—is considered a 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. Feeling encodes biological value—it biases regulation, orientation, and adaptation. Processes such as homeostasis, chemotaxis, and stress-induced gene expression exemplify how valence appraisal shapes behavior and internal dynamics. In this view, feeling is not a consequence of cognition but its evolutionary foundation.

While sensing detects external or internal conditions, feeling assigns relevance and value, thereby guiding decision-making and regulation. Without this evaluative layer, sensory input would lack behavioral significance. A system that senses but does not feel would process information without any basis for selection, preference, or prioritization. Feeling introduces directionality, allowing the system to relate to the world through internally meaningful distinctions. 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 [1,2].

This perspective aligns with insights from Antonio Damasio [3,4], who argues that feelings arise from the internal mapping of bodily states, and with Mark Solms [5], 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 research by Pamela Lyon and collaborators [6], 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 by Kevin Laland and collaborators [7] and the conceptual frameworks of Denis Noble [8] and Simona Ginsburg and Eva Jablonka [9], which highlight cognition as an intrinsic feature emerging early in life's history. We build on cellular-molecular mechanisms in epigenetic evolutionary biology [10], with a focus on cognition-based evolution [11]. We also draw from the pioneering work of Michael Levin, who demonstrates bioelectrical and morphogenetic signaling as foundational to cellular and tissue-level cognition [12,13], and from Guenther Witzany's insights on biological communication and signaling processes as essential for life and cognition [14]. These biological insights are continuous with theories of embodied cognition [15], enactivism [16], developmental systems theory [17], and basal cognition [18], together situating cognition as a multi-level, embodied, and evolutionary process tightly linked to the regulation of living systems.

This approach conceptualizes cognition not as manipulation of symbols, but as the lived regulation of life processes, which can be modelled within the Info-Computational (ICON) framework [19], with physical structures and informational flows as 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.

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

While many traditional cognitive science frameworks begin with consciousness or symbolic reasoning, recent theoretical models propose that a minimal form of subjectivity—proto-subjectivity—is intrinsically linked to the emergence of cognition itself [1,6,19,20]. Rather than treating proto-subjectivity as a precursor to cognition, the two are seen as 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 results in embodied interactions with the environment—expressed through selective sensitivity, norm-driven regulation, and recursive self-maintenance. Based on minimal agency theories [1] this framing emphasizes normativity and self-maintenance as key features of cognitive systems.

Evidence of this co-emergent dynamic can be observed in simple organisms, where adaptive behaviors—such as bacterial chemotaxis or gene regulation under stress—reflect both environmental processing and a form of internal evaluative concern, even in the absence of a nervous system [21,22]. The internal organization of such systems embeds preferences, viability thresholds, and constraints that guide action—not through explicit intention, but via physically grounded, feedback-driven regulation. Cognition is not layered atop life but immanent within it—an affectively modulated process intrinsic to biological structure and function.

This account draws on the minimal agency framework articulated by Barandiaran et al. [1], which defines cognitive systems by four criteria: individuality (self/non-self—distinction), normativity (value-based regulation), asymmetry (cause-effect directionality), and spatiotemporal cohesion (continuity through time and structure). These criteria are fulfilled by unicellular and multicellular systems, whose behaviors demonstrate homeostatic regulation, valence-sensitive signaling, and morphological adaptation—characteristics consistent with proto-subjective cognition. In the case of organisms capable of "unlimited associative learning" (all vertebrates, many arthropods, and some cephalopod molluscs) the origins of subjectivity proposed by Ginsburg and Jablonka [9], is in the evaluative, goal-directed dynamics of early life forms.

The info-computational framework (ICON) supports this model by describing living systems as self-modifying, morphologically computing agents [2,23]. These systems continuously restructure their internal architecture in response to external stimuli and internal states, thereby computing their own future configurations. Within this model, Dodig-Crnkovic [2] argues for a spectrum 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.

Proto-subjectivity is thus not speculative but empirically grounded in well-documented regulatory behaviors. It can be identified through a combination of observational and functional criteria, including:

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 maintain viability. This is the root of meaning in biological systems—not symbolically represented but embodied in affectively regulated behavior. This does not imply phenomenological consciousness in unicellular life. Rather, it highlights that cognition may begin as a sensitivity, with an evaluative and self-regulating function of feeling internal conditions and environmental relations. Proto-subjectivity provides a biologically grounded foundation for understanding cognition as a continuous, affectively modulated regulation of life, rather than a capacity limited to abstract, symbolic problem-solving.

4. The Basal Roots of Cognition

A fundamental shift in perspective suggests that cognition does not begin in the neocortex or brain, but rather emerges at the cellular level, as part of life's basic regulatory architecture. The cellular and non-neural basis of cognition has been extensively developed in the work of Pamela Lyon and Michael Levin, who argue that biological regulation, perception, and memory are present even in simple living systems. Michael Levin's research [20,22] demonstrates that bioelectrical signaling across tissues encodes pattern memories, supports goal-directed repair, and regulates behavior during morphogenesis and regeneration. Pamela Lyon and collaborators [6] introduce 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, in agreement with Maturana & Varela [24]. 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, in a goal-directed manner. Levin's experiments with planaria reveal that regeneration follows bioelectrical pattern memories rather than being fully determined by genetic coding—suggesting a distributed cognitive process operating at the tissue level [12,22]. These findings support the view that information in biological systems is stored and processed in a distributed, concurrent way, consistent with broader models of embodied and collective cognition [13,22]. Levin's more recent work [20] 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. [22] argue that cognition is grounded in bioelectric and morphological computation, enabling cells to act as agents embedded in dynamic fields of constraints and affordances.

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

Classical computational models, such as the Universal Turing Machine, fall short in capturing the embodied, self-organizing, adaptive complexity of biological systems. Organisms are not passive processors of input—they are self-organizing, adaptive, and creative systems. Hava Siegelmann [25] has shown that biological adaptation, choice, and learning exceed the bounds of fixed algorithmic computation, highlighting the need for natural computation.

George Kampis [23] proposes that biological organisms can be modeled as component-systems—that is, self-referential, self-modifying computational entities capable of recursively rebuilding both their hardware (structure) and software (regulatory logic). As Kampis [23] (p. 223) writes:

> "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."

In contrast to fixed-rule machines, such systems not only process information but also reconstruct their own internal architecture. This recursive self-modification is essential for the developmental plasticity, creativity, and evolvability observed in living systems.

Focusing on real-time information-processing aspects, Carl Hewitt's Actor Model [26] 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. Both the Actor Model and component-systems models emphasize concurrency, structural flexibility, and embodied processing, aligning them more closely with the computational behavior of living organisms.

This shift reflects an expanded view of computation, as outlined by Burgin and Dodig-Crnkovic [27,28], who describe a spectrum of computational architectures: from algorithmic and symbolic models to interactive, morphological, and self-organizing systems. Their computational taxonomy shows how biological systems exemplify natural computation, where information flow, structure, and value-regulation co-evolve through morphological and affective adaptation. 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 also have implications for artificial intelligence, particularly in the development of adaptive, embodied, and self-modifying systems. Contemporary AI systems, largely modeled on disembodied symbol processing, could benefit from biologically inspired architectures grounded in affective regulation and morphological computation, and recursive self-construction. 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 [19,29] 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 presents types of computation in biological systems.

Table 1. Types of Computation in Biological Systems [1].

Computation	Definition	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	Dodig-Crnkovic [29]
Bioelectric/Self-modifying	Recursive reconfiguration of structure and behavior based on internal feedback	Regenerative repair in planaria, tissue morphogenesis	Kampis [23], Levin [20]
Info-computation	Integrated processing of form, information, and value-regulation	All levels of life—cells to cognition	Dodig-Crnkovic [2,29]

[1] Morphological, Bioelectric, self-modifying and info-computational models are all sub-symbolic.

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

From the evolutionary perspective, cognition does not begin with abstract reasoning or conscious deliberation but emerges gradually from more fundamental biological processes. 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, which according to Maturana and Varela [24] is coextensive with life.

Affect functions as a regulatory interface, integrating internal states and environmental signals to maintain systemic coherence. Emerging from layers of sensing and feeling, it allows organisms to bias responses, prioritize behaviors, and modulate activity dynamically. 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. As Damasio and Lyon suggest, to sense is already, in some form, to judge [3,6]. A bacterium swimming toward nutrients is not merely reacting; it is expressing a preference shaped by internal metabolic states and historical feedback [22,24]. This basic form of valence-guided behavior reflects a proto subjectivity:

the system's capacity to relate to the world from its own organizational standpoint, shaped by viability norms and prior experience [1]. 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 [5,30].

As Damasio [3,4], Solms [5], and Friston & Seth [30] argue, affective dynamics precede representational cognition and are rooted in the organism's ongoing internal mapping of its own physiological states, and anticipated futures. 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.

While affective regulation is often associated with homeostasis, viability also depends on behavioral flexibility and future-oriented exploration, especially in more complex systems. The Free Energy Principle (FEP) and Active Inference models extend homeostatic regulation into *allostasis*, or the anticipation of future needs through proactive action [31].

Some critics argue that The Free Energy Principle rules out the possibility of novelty and complexity, since it seems to imply that biological systems aim only to reduce long-term surprise in order to preserve homeostasis. More recent interpretations, however, indicate that surprise minimization can inherently give rise to exploration and incentives for novelty. Within this framework, agents choose policies that minimize surprise by reducing the divergence between expected and preferred outcomes. This process entails both exploiting high-utility goal states and exploring alternative possibilities. Importantly, encountering new states enhances the value of the current one. According to Schwartenbeck and colleagues, formulating decision-making in variational terms suggests that behavior is driven jointly by the entropy and expected utility of potential future states, reconciling surprise minimization with curiosity and exploration rather than opposing them [32].

On the other hand, Ramírez-Ruiz et al. [33] propose the Maximum Occupancy Principle (MOP), which characterizes complex behavior as the agent's capacity to maximize the entropy of its future action-state trajectories. This highlights the generative, open-ended dimensions of cognition, in which intrinsic motivation is not only reactive but expands the space of viable futures.

Kampis's [23] model of self-modifying systems supports this dynamical view of cognition: 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.

In Table 2, *Sensing* involves signal detection and may include adaptive feedback but does not imply value appraisal. *Feeling* can occur without immediate action (e.g., metabolic distress signaling). *Affect* includes regulation. *Emotion* requires neural orchestration and supports complex behavioral integration

Table 2. The Affective Ladder of Cognition.

Layer	Definition	Examples	Biological Level
Sensing	Detection of internal or external stimuli	Chemoreception, mechanoreception	From single cell to multicellular
Feeling	Basic valence-based appraisal of stimuli	Chemotaxis toward nutrients, stress-induced gene expression	Single cells, plants, animals

Table 2. *Cont.*

Layer	Definition	Examples	Biological Level
Affect	Regulation of internal state based on value appraisals	Homeostasis, bioelectrical modulation	Tissues, organs
Emotion	Coordinated affective states with physiological and behavioral change	Fear, pleasure, arousal	Nervous-system-based organisms

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, as shown by Candace Pert [34].

This molecular continuity strongly supports the thesis that emotion, in its most basic form, is not a human characteristic, 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 [33] refers to such mechanisms as evidence for proto-emotional behavior, rooted in the capacity for physiological self-regulation and environmental responsiveness as part of basal cognition.

These systems exhibit 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 and brains. This reinforces the central claim in basal cognition and affective neuroscience that feeling is evolutionarily primary and precedes more complex forms of cognition.

For example, research shows that unicellular organisms possess molecular systems homologous to those regulating affect in vertebrates—the biochemical substrates of affective regulation—neurotransmitters, hormones, and neuromodulators. These findings suggest that the roots of affective processes are evolutionarily ancient, predating the emergence of neural circuits.

One of the best-studied examples is the ciliate Tetrahymena. It possesses opioid receptors that respond not only to endogenous opioid peptides but also to mammalian opioid drugs [35]. The pharmacological properties of these receptors closely resemble mammalian μ-opioid receptors: they exhibit tolerance under chronic stimulation and even withdrawal-like responses when agonists are removed. This demonstrates that unicellular organisms can undergo state-dependent modulation of behavior via conserved molecular pathways.

Beyond opioids, Tetrahymena also produces and responds to a wide range of hormones and neurotransmitters, including insulin, melatonin, histamine, and serotonin [36]. These molecules influence cellular metabolism, reproduction, and adaptive responses. Their functional similarity to vertebrate hormonal systems highlights the deep continuity of biochemical regulation across evolutionary scales.

Taken together, these findings show that the molecular machinery of affect—chemical systems that encode valence, regulate internal states, and bias behavior—was present long before the emergence of nervous systems. Affect is not a late addition to cognition, but its biochemical foundation, shaping adaptive behavior even in the simplest living organisms.

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

Intelligence is not localized only in the brain, as often assumed; it is distributed throughout the living organism as a network of valenced, goal-directed information-processes. Organisms use morphology as a medium of computation—not only to carry out actions but to encode and regulate future states through form-dependent information processing, including memory.

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 these systems, the body does not merely represent environmental inputs. Rather, it directly engages with the environment through feedback loops embedded in material properties, a process known as morphological computation [12,20,37]. Michael Levin [20] 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 [38] 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 [29], 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.

Cognition and Intelligence: Navigating Problem Spaces

Cognition is the embodied, affect-regulated process by which living systems sense, evaluate, and interact with their environments. Intelligence is defined as the capacity to solve problems across multiple domains or spaces, not by executing fixed rules, but by reconfiguring strategies, structures, or behaviors in response to changing constraints. Following Michael Levin's work [13], this includes morphospace (the space of possible bodily forms), physiological space, behavioral space, and even goal space.

Intelligence is not defined by abstract reasoning or language, but by adaptive versatility—the ability to achieve viability-preserving outcomes under diverse and dynamic conditions. A regenerative organism, for example, may solve the problem of injury by navigating morphospace to reconstruct missing structures—an act of embodied intelligence grounded in bioelectric pattern memory [12]. 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 [39] evolutionary account of cognitive architectures that evolve increasing layers of control and representation, enabling organisms to handle novel, nested, and abstract problems.

8. Conclusion. 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 abstract algorithms or symbolic logic, but from the recursive organization of life itself—from the capacity to sense, evaluate, and reorganize. This entry presents the view that proto-subjectivity and basal 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.

Cognition is grounded in the organization and regulation of living systems, emerging through the dynamic interplay of sensation, affective valuation (feeling), adaptive regulation (affect), and emotion. The biochemical substrates of affect—neurotransmitters, hormones, and neuromodulators—are present even in unicellular organisms, where they regulate adaptive behavior. This indicates that affect is not a late evolutionary development but a foundational property of life, providing continuity from unicellular affective chemistry to the emergence of emotion in complex nervous systems.

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 Daniel Kahneman [40] 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 with living systems that feel, regulate, and reconstitute themselves in relation to the world.

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.

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.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing does not apply to this article.

Acknowledgments: The author wishes to express gratitude to Katherine Peil Kauffman for her insightful comments on my earlier work, including suggestion of important references, which initiated the development of the present article.

Conflicts of Interest: The author declares no conflicts of interest.

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