From Shadow to Substance: The Sentient Principle as a Unified Framework for Sentience Across All Life

Wu Jingyu
Independent Researcher

Abstract

Current debates surrounding “basal cognition,” “minimal cognition,” “plant intelligence,” and “consciousness” remain mired in terminological disputes, with disputants arguing over definitional boundaries rather than engaging with the biological phenomena themselves. This paper proposes a meta-theoretical framework grounded in the “Sentient Principle,” shifting the focus of cognitive research from the shadow of classificatory disputes—definitions, analogies, and phenomenological labels—back to the substance itself: the observable biological reality of sentient life.

We advocate the “sensation-behavior loop” as the foundational unit for understanding sentience across all life, providing a coherent explanatory framework from unicellular organisms to human cognition. By distinguishing between “value-based selection” (one-time physicochemical execution of innate programs) and “value-dependent selection” (iterative consolidation based on experiential feedback), we elucidate the essential difference between adaptive flux and genuine learning, and introduce “iterative depth” and “memory depth” as measurable parameters of learning capacity. We further propose that the qualitative leap in human cognition is enabled by “perimpletion”—the extension of the sensation-behavior loop beyond individual boundaries through tools, symbols, and cultural transmission—a concept developed from Feigenberg’s (2006) work on Homo sapiens perimplens.

We argue that all empirical research should be evaluated by a single criterion: does it illuminate how an organism senses, is driven by, and acts to resolve states of unease relative to its three fundamental tensions—defensive, aggressive, and empathetic? Ultimately, we call for a shift from terminological disputes to direct engagement with the biological reality of sentience as a universal property of life.

Keywords

Sentient Principle; basal cognition; sensation-behavior loop; innateness priority; value-based selection; value-dependent selection; sentience spectrum

1 Introduction: Standing Above the Shadow, Questioning the Substance

Over the past two decades, debates about plant cognition, unicellular intelligence, and even universal consciousness in life have proliferated. Concepts such as "plant neurobiology," "plant intelligence," "basal cognition," and "minimal cognition" have been repeatedly proposed, defended, and criticized. Proponents, citing behavioral complexity, extend terms like learning, memory, and decision-making to non-neural organisms; opponents, citing structural differences, insist these abilities must depend on nervous systems. Both sides hold their ground, and the debate often degenerates into a game of definitions: one side uses functional definitions, the other mechanistic definitions, and neither can convince the other.

The root of this predicament lies in the fact that *we focus excessively on the "shadow" cast by life—the observable behaviors, measurable signals, and analogous phenomena—while neglecting the "substance" itself that casts the shadow: a living, sentient system.* As the late ethnobotanist Timothy Plowman once said: "They can eat light, isn't that enough?" The greatness of plants lies not in whether they possess our definitions of "consciousness" or "learning," but in how they fulfill the fundamental tasks of life in their own unique way.

The "Sentient Principle" is proposed precisely to address this predicament. It refrains from participating in the demarcation of terminology and instead returns to the most fundamental mode of existence: the *sensation-behavior loop*. This paper aims to use the Sentient Principle as its core, integrating our discussions on sentience from unicellular organisms to humans, to construct a unified framework for sentience across all life, pulling research from the "shadow" back to the "substance."

2 Core Concepts of the Sentient Principle: Reinterpreting from Shadow to Substance

2.1 Sensation-Behavior Loop: From "Stimulus-Response" to a Closed Loop of Life

Traditional behaviorism simplifies life activities into a linear "stimulus-response" chain: an external stimulus inevitably triggers a fixed response. While convenient for experimental manipulation, this model fragments the living stream of life into isolated segments, ignoring the most essential characteristic of life—*the loop*.

The Sentient Principle redefines the basic unit of life as the "sensation-behavior loop": sensation drives behavior, behavior generates new sensations, and the cycle continues indefinitely. This is not a simple feedback loop but a closed loop: the outcome of each behavior becomes the starting point for the next sensation, and each sensation carries traces of previous cycles.

Implementation in non-neural systems: Take bacterial chemotaxis as an example. When a bacterium senses an increase in attractant concentration, it suppresses tumbling and continues swimming straight; when it senses a repellent, it activates tumbling to change direction. During this process, the methylation state of receptors (CheR/CheB system) continuously adjusts, allowing the bacterium to maintain sensitivity over a wide range of background concentrations. This is a complete sensation-behavior loop: sensation (chemical gradient) → behavior (adjustment of flagellar rotation pattern) → new sensation (concentration at new location) → receptor state adjustment (preparing for the next sensation). The entire process requires no neurons yet achieves adaptive behavior.

The chemotaxis of slime moulds is even more intuitive. When a local region senses food, its oscillation frequency increases, attracting protoplasmic flow toward that region; upon reaching the food source, new sensations (nutrient intake) subsequently influence exploration behavior. Every oscillation, every flow, is part of the loop.

Biological significance: The sensation-behavior loop enables life to continuously track environmental changes and adjust behavior in real-time, rather than passively waiting for the next stimulus. It is the root of life's agency—even in a "resting" state, the loop continues (e.g., endogenous oscillations), keeping life always in a state of "readiness to respond."

Cross-level extension: From bacteria to humans, all life takes the sensation-behavior loop as its basic unit. Human reflection, dialogue, and creation are merely extensions of this loop at higher levels—every thought is an inner sensation driving inner behavior, and every expression is an external manifestation of the inner loop.

2.2 Three Basic Tensions: The Source of Life's Dynamics

All sensation-behavior loops serve three fundamental survival needs. These three tensions are not post-hoc categories but fundamental challenges that life must face from its inception.

Defensive Tension: Maintaining boundary integrity. All life must maintain the boundary between itself and the environment. For unicellular organisms, this is the integrity of the cell membrane; for multicellular organisms, this is the function of the body surface and immune system. When boundaries are threatened, life experiences sensations such as pain, fear, and disgust, driving avoidance or counter-attack behaviors.

Aggressive Tension: Acquiring energy resources. Life is a dissipative system that must continuously obtain energy from the environment to sustain itself. When energy is lacking, life experiences sensations such as hunger, thirst, and fatigue, driving foraging, drinking, and resting behaviors.

Empathetic Tension*: Sustaining rhythm and race. Life exists in time and must maintain synchrony between its internal rhythms and environmental cycles, as well as perpetuate the race through reproduction. When rhythms are disrupted,

* The term "empathetic tension" is adopted from the "Three Layers, Nine Categories" developed in Wu (2026), where it refers specifically to the organism's drive to maintain internal rhythmic synchrony and ensure species continuity, distinct from its common usage in psychology as interpersonal empathy.

life experiences drowsiness; when reproductive opportunities arise, it experiences sensations such as sexual desire and attachment.

Flux of priorities: The priorities of the three tensions are not fixed. Generally, defensive takes precedence over aggressive, which takes precedence over empathetic—because boundary breach is immediately fatal, energy depletion is slower, and rhythm disruption is even slower. However, this priority fluxes in specific contexts. For example, slime moulds can regenerate or fuse after being cut—a characteristic of their multinucleate structure, illustrating that "boundary integrity" in the defensive sense is not the rigid "avoidance of individual injury" but the maintenance of "systemic integrity." More crucially, when nutrient deprivation threatens survival, empathy (spore formation) may reverse the priority: individual survival yields to race perpetuation. The priorities of the three tensions flux in context—this is the core dynamic view of the Sentient Principle.

Biological significance: The three tensions provide value orientation for all life behaviors—what is "good" and what is "bad" can ultimately be traced back to the satisfaction or threat of these fundamental needs. They are the foundation of "value system sensation."

2.3 Value System Sensation: From "Innate Baseline" to "Acquired Flux"

Traditional cognitive science views "value" as a subjective, difficult-to-quantify attribute. However, the Sentient Principle reduces it to a comprehensible biological concept.

Innate value system sensation is a set of value baselines endowed by evolution. It is encoded in genes, the crystallization of billions of years of natural selection. For example, slime moulds' attraction to glucose, avoidance of bright light, and aversion to salt are all innately preset. These baselines require no learning; life knows from birth what is "good" and what is "bad."

Acquired value system sensation is a threshold variation based on the innate baseline. Individual experience can adjust response sensitivity but cannot change the direction of value. Slime mould habituation to salt is a typical example: after repeated exposure to salt, the aversive response diminishes—this results from an upward threshold adjustment, but the innate baseline "salt is harmful" never changes. When salt is excreted, the threshold recovers, and the aversive response reappears. This is a "fine-tuning without altering the basic design."

Biological significance: The innate baseline ensures life can respond correctly even in situations it has never encountered (avoiding salt upon first exposure); acquired flux allows life to temporarily adapt in unavoidable environments (tolerating when trapped in a saline area). Their combination achieves a unity of stability and flexibility.

Empirical evidence: The study by Boussard et al. (2019) perfectly illustrates this distinction. Habituated individuals had intracellular sodium concentrations ten times higher than controls, positively correlated with the degree of habituation; when sodium was excreted, habituation disappeared. This is the physical basis of "acquired flux"—material retention leads to threshold changes, yet the innate baseline "salt is harmful" remains unchanged.

2.4 Sensation Discrepancy: The Core Driver of Learning

Traditional learning theories attribute learning to external factors like "reinforcement" or "repetition," neglecting internal drives. *The Sentient Principle locates the driver of learning within life itself—namely, "sensation discrepancy."*

Sensation discrepancy is defined as: *the internal tension generated when a discernible imbalance occurs between immediate sensation and anticipatory sensation.* It is not a direct result of external stimuli but a product of internal comparison. Based on the clarity of anticipatory sensation, it can be divided into two types.

Initiating sensation discrepancy occurs at the most vague end of anticipatory sensation. Here, anticipation corresponds to "innate value system sensation"—value baselines endowed by evolution, such as "energy should be sufficient" or "boundaries should be intact." When blood sugar drops, immediate sensation falls out of balance with this vague baseline, producing hunger—a vague discomfort with no specific direction, yet it drives the system into an exploratory state, activating past traces in "the remembered present" and prompting anticipatory sensation to begin emerging from chaos.

Verifying sensation discrepancy occurs when anticipatory sensation has become relatively clear. Here, anticipatory sensation has progressed from the vague value baseline, via the re-sensing of past traces in "the remembered present," to a "goal-directed anticipation" with clear direction. This process of clarification is precisely the essence of "learning"—*the enhancement of anticipatory sensation in clarity and precision.* Sensation discrepancy is the fundamental driver of this enhancement process.

This process manifests differently at different levels of life:

- **In non-neural organisms such as slime moulds**, the clarification of anticipatory sensation often originates from the direct effect of material retention or structural traces. For example, repeated exposure to salt increases intracellular sodium concentration (a trace), and the system's aversion threshold to salt rises accordingly, forming a vague anticipation that "the current environment is salt-harmless"—a recalibration of stimulus value, not a prediction of a specific event. When the environment changes (salt removed), sodium concentration drops, immediate sensation imbalances with this state, and the system recovers the aversive response—this is a primitive form of verifying sensation discrepancy. There is no term "learning" here, but it clearly demonstrates the essence of "enhancement of anticipatory sensation in clarity and precision"—from the initial "salt is harmful" (innate baseline) to "currently tolerable" (threshold flux), and back to "salt is harmful" after recovery, anticipatory sensation continuously adjusts in flux.

- **In animals with nervous systems**, the clarification of anticipatory sensation depends on the iterative consolidation of "value-dependent selection" and the real-time integration of "the remembered present." Take humans as an example: after repeatedly experiencing the event "open refrigerator → see apple," each experience leaves a trace in the nervous system. When facing a similar situation again (e.g., hungry), past traces are re-sensed in "the remembered present," integrating in real-time with current immediate sensations (refrigerator appearance, hunger level), generating a clear goal-directed anticipation that "there should be an apple in the refrigerator"—an anticipation with clear spatial (refrigerator) and content (apple) direction. Upon opening the refrigerator and finding it empty, immediate sensation strongly imbalances with this clear anticipation, producing disappointment. This verifying sensation discrepancy drives the system to update the anticipation (e.g., "next time, don't expect an apple, or expect needing to buy one"), further adjusting anticipatory sensation in clarity and precision.

Key point: The core of verifying sensation discrepancy lies in the "comparison between immediate sensation and clear anticipation." This comparison always occurs in the "present," and the clear anticipation itself is a reconstruction of past traces in the present. Whether in neural or non-neural life, this mechanism is universal, differing only in implementation complexity. The underlying principle is the core insight of the Sentient Principle: *Learning is not the accumulation of static knowledge, but the continuous enhancement of anticipatory sensation in clarity and precision; sensation discrepancy is the fundamental driver enabling this enhancement.*

Biological significance: Sensation discrepancy enables life to detect "surprise," thereby adjusting anticipation and updating models. It is the engine of adaptation, allowing life to continuously optimize its anticipations in a changing environment to better predict the future and guide behavior. Without sensation discrepancy, life would cling to existing patterns and be unable to cope with change.

2.5 Trace and Re-sensing: From "Memory" to the Physical State Substance Return

In traditional cognitive science, "memory" is understood as the storage and retrieval of information, while "recall" is retrieving a copy of information from the storage repository. This understanding treats memory as an abstract, symbolic "shadow," ignoring its physical reality in living systems.

The Sentient Principle reduces "memory" to "trace"—the physical state left in a system by past "sensation-behavior loops." Such traces can take many forms: in slime moulds, they are intracellular sodium ion concentration (Boussard et al., 2019), thickened tubular network structures (Kramar & Alim, 2021), or chemical imprints in extracellular slime (ECS) (Reid et al., 2012); in animals, they are changes in synaptic connection strength. Regardless of form, the essence of a trace is physical and measurable, not a mysterious "storage."

Correspondingly, "recall" is reinterpreted as "re-sensing"—the process by which a system *creatively reconstructs* a trace upon re-encountering it. This is not retrieving an original from a database but a creative re-enactment of past experience based on the present state.

2.5.1 Trace Externalization at the Individual Level: Slime Mould Extracellular Slime

Slime mould extracellular slime (ECS) is a classic case of "trace externalization." Reid et al. (2012) showed that slime moulds leave ECS traces while exploring their environment. Upon re-encountering these traces, they can "re-sense" past exploratory experiences, navigating more efficiently in complex environments. This is not only a medium for social interaction—the biological significance of ECS for social recognition—but also a form of memory externalization at the individual level: *it "offloads" internal spatial memory onto the external environment, enabling the organism to use these external traces to guide future behavior.*

The biological significance of this externalized memory lies in reducing the internal memory burden while allowing memory to dynamically adjust with environmental changes. When ECS traces are covered or disappear, "memory" accordingly fades—again confirming the essence of "material retention": trace present, memory present; trace lost, memory lost.

2.5.2 Symbolic Memory at the Cultural Level: Vygotsky's Insight

Vygotsky elevated this "trace externalization" to an entirely new level. As documented by Gippenreiter (2008)—a student of Leontiev and a direct inheritor of the Vygotsky-Leontiev-Luria tradition—Vygotsky analyzed widely used mnemonic techniques such as "tying a knot to remember": a person ties a knot in a handkerchief, and upon seeing it again, recalls the planned matter.

From ethnographic materials, Vygotsky found that tribes without written language widely used similar memory methods: notches on trees, various shapes and combinations of incisions; knotted cord systems—a series of knots tied on a string to "record" information; and various other external tools. He recounted a vivid example*:

> *When Arseniev visited an Adyghe village, the locals asked him to inform the Vladivostok authorities about the cruelty of the outside headman Tau Ku. An old, gray-haired man stepped forward from the crowd, handed him a lynx paw, and said: "Put this paw in your pocket. When you get there, let this paw remind you what to say about the outsiders' cruel abuses."*

In these cases, external tools serve as memory vehicles—sometimes simple symbols (knot, paw) associable with any content; sometimes more elaborate systems (various notches, node systems) more closely related to the memorized content, representing precursors to writing. But these differences are secondary, incidental. The important and universal point is: *these tool-symbols, through their presence and use, create a new structure of memory as a psychological process.*

2.5.3 A Continuum from Natural Traces to Cultural Symbols

Juxtaposing slime mould ECS with Vygotsky's external tools reveals a continuum from natural traces to cultural symbols:

Dimension	Natural Trace (ECS)	Cultural Symbol (Knot/Lynx Paw)
Origin	Natural byproduct of behavior	Active cultural creation
Relation to Signified	Causal link (left by passing through)	Arbitrary link (conventional)
Mode of Interpretation	Automatic, unconscious	Requires cultural learning
Function	Guide adaptive behavior	Bear meaning, communicate ideas
Level	Vital/Social stratum germ	Noetic/Cultural stratum

Common essence: Both are "traces"—physical states left in the external world by past experience. Upon re-encounter, the system performs "re-sensing"—

* Gippenreiter (2008) represents a primary source within the Vygotsky-Leontiev-Luria tradition: as a student of A. N. Leontiev, she had direct access to unpublished manuscripts and oral traditions of the school, making her documentation of Vygotsky's analyses authoritative beyond a typical textbook.

slime moulds through automatic physiological responses, humans through conscious symbolic interpretation. This process is always *physical, substantial*, not a mysterious "information retrieval."

2.5.4 Trace Persistence and Memory Depth

The persistence of a trace determines "memory depth," a crucial parameter of learning ability. Slime mould trace persistence ranges from seconds (oscillation phase) to days (network structure), limiting the complexity of learning they can support. Humans, through cultural perimpletion, extend trace carriers to tree notches, knotted cords, books, and databases, achieving intergenerational transmission and thus almost unlimited memory depth. The lynx paw in Arseniev's pocket carries a people's suffering memory across time and space to a distant place—this is the ultimate expression of "re-sensing" at the cultural level.

2.6 The Remembered Present: From "Linear Time" to Real-time Integration

Traditional conceptions of time view past, present, and future as linearly arranged dimensions: the past is gone, the future has not yet arrived, only the present is real. While aligning with everyday experience, this view cannot explain a fundamental fact: *the behavior of life at any moment is simultaneously influenced by past experience, present feeling, and future anticipation.*

The Sentient Principle defines this real-time integration process as "the remembered present." Each moment's experience is the real-time intersection and mutual modulation of the past (trace re-sensing), the present (immediate sensation), and the future (anticipatory sensation). We never live in the "pure present" but always reside within a dynamic field interwoven by three temporal dimensions.

Implementation in non-neural systems: Take the periodic anticipation experiment in slime moulds (Saigusa et al., 2008). After being repeatedly exposed to cold, dry air at fixed intervals three times, at the fourth anticipated time point, even without stimulation, they spontaneously slow their movement. The core mechanism: the three prior stimuli leave traces in the system (likely modulation of oscillation phase); at the fourth time point, immediate sensation (current environmental state) integrates in real-time with anticipatory sensation generated from past traces ("stimulus impending"), driving behavioral adjustment. When stimulation consistently absent, traces gradually fade, and anticipation accordingly disappears. The entire process perfectly embodies the integration of "past (traces)—present (immediate sensation)—future (anticipation)" in the present.

Biological significance: The remembered present enables life to integrate disparate temporal experiences into unified action decisions. It is not passive recording of the past nor empty imagination of the future, but *an active process of weaving past and future into the present.* This ability allows life to learn from experience and prepare for the future while always anchored in the reality of the present.

Cross-level extension: Take everyday human experience. When someone walks into their usual café, they are not merely "seeing" the scene. Traces from countless past visits (coffee aroma, familiar layout, staff faces) are re-sensed in "the remembered present"; their current immediate sensations (today's sunlight, bodily fatigue) integrate in real-time with these traces; simultaneously, their anticipation of the coffee they are about to drink (taste, temperature) is generated in the present, driving them to their familiar seat and ordering their usual drink. Past, present, and future converge in this moment, constituting the complete experience of walking into the café. This vividly illustrates "the remembered present" at the human level: *life perpetually lives within the real-time integration of "past (trace re-sensing)—present (immediate sensation)—future (anticipatory sensation)," writing its existence in the flux of sensation.*

2.7 Value-based Selection and Value-dependent Selection: From "Learning" to Two Fundamental Mechanisms

The traditional concept of "learning" lumps various behavioral changes into one category, ignoring two fundamentally different mechanisms. *The Sentient Principle explicitly distinguishes between "value-based selection" and "value-dependent selection."* The former is a physical mechanism, the latter genuine learning.

Dimension	Value-based Selection	Value-dependent Selection
Essence	One-time execution of innate program	Iterative consolidation based on experiential feedback
History Dependence	None: outcome determined by present state	Present: outcome depends on past experience
Iterativity	One-time, no repetition needed	Requires repeated pairing, feedback optimization
Trace Formation	Direct result of physical state	Consolidation of new traces (e.g., synaptic plasticity)
Reversibility	Reversible (recovery after material excretion)	Reversible (extinction), but traces can persist long-term
Examples	Network optimization, mitochondrial DNA elimination, habituation (material retention)	Classical conditioning, operant conditioning
Requires "Learning"	No (physical mechanism)	Yes (genuine learning)

Value-based selection is a one-directional choice based on innate value baselines, directly driven by physicochemical mechanisms. Slime mould network optimization is a typical example: high-flow tubes thicken, low-flow tubes atrophy—a direct result of hydrodynamic positive feedback, requiring no "evaluation" or "choice." Mitochondrial DNA elimination similarly: upon fusion, a molecular program controlled by a nuclear gene locus executes a one-time ruling—mitochondrion A is retained, mitochondrion B is digested. Habituation (material retention) also falls under value-based selection: salt inside the cell, behavior changes; salt excreted, behavior recovers. This is "flux," not "consolidation."

Value-dependent selection is iterative consolidation based on experiential feedback, requiring repetition, history dependence, and formation of new traces. Animal classical conditioning is a typical example: after multiple pairings of a bell with food, the bell alone elicits salivation—this is the formation of a new trace, genuine "learning." Operant conditioning similarly: lever-pressing behavior is reinforced by food delivery, consolidating the behavioral pattern. This process requires iteration (multiple repetitions), history dependence (past successes influence future choices), and formation of new traces (synaptic plasticity).

Iterative Depth and Memory Depth: Core Parameters of Learning

The capacity for value-dependent selection is not unlimited; it is constrained by two core parameters:

- **Iterative depth**: The ability to perform multiple rounds of optimization based on past experience, manifested as the order of conditioned reflexes. Zero-order: no iteration (e.g., all slime mould choices are one-time); first-order: adjustment based on single experience (habituation, still flux, not genuine learning); second-order: using first-order outcomes as new starting points (first-order conditioning); third-order and above: multi-level recursion (higher-order conditioning).
- **Memory depth**: The timescale over which memory traces can persist, determining the possibility of iteration. Seconds-minutes (oscillation phase traces) support only instantaneous responses; minutes-hours (molecular distribution traces) support flux; hours-days (ECS traces) might support simple learning; days-years (synaptic traces) support multi-order learning; intergenerational (cultural traces) are unique to humans.

Key formula: Possible order of conditioning ≤ Iterative depth × Memory persistence coefficient.

This formula reveals the fundamental constraints on learning: even if iterative depth is sufficient, if memory traces decay too quickly (insufficient memory depth), higher-order conditioning cannot be established. Conversely, even with persistent memory, lacking iterative capacity (zero iterative depth) prevents genuine learning. Slime moulds possess abundant value-based selection but zero iterative depth, thus stopping at “flux,” unable to enter the “consolidation” learning level. Humans, through cultural perimpletion, extend memory depth intergenerationally, enabling iteration to transcend individual lifespans, achieving the leap from “value-based selection” to “value-dependent selection,” and constructing the magnificent edifice of science, art, philosophy, and civilization upon this foundation.

Biological significance: Distinguishing these two reveals the essential difference between “adaptation” and “learning.” Value-based selection enables life to cope with common situations most economically, without expending energy maintaining complex memories; value-dependent selection enables life to handle variable environments, optimizing behavioral strategies from individual experience. The former is evolution's pre-set "insurance," the latter acquired "flexibility."

Empirical evidence: Slime moulds possess abundant value-based selection mechanisms but lack confirmed value-dependent selection. Boussard et al. (2019) perfectly illustrates this: habituation arises from material retention, requiring no repeated pairing; a mere 2-hour forced absorption induces it, without needing iteration; upon material excretion, behavior recovers, leaving no persistent trace. This exemplifies "value-based selection" and explains why slime moulds consistently fail to exhibit classical conditioning—they lack the key of "iteration."

2.8 Perimpletion: From "Tool Use" to "Self-Boundary Expansion"

The most distinctive feature distinguishing humans from other life is not merely possessing a complex brain, but *the ability to externalize their own "traces" into the world and then internalize that externalized world as new "objects of sensation."* Feigenberg termed this process "perimpletion".

Essence of perimpletion: Extending the sensation-behavior loop, originally confined within the individual, beyond the individual through external tools, symbol systems, and technological means. Each act of perimpletion is an expansion of the "self-boundary" —we are no longer merely a "body-brain" complex but a perimplent system of "body-brain-tool-symbol-technology."

Levels of perimpletion:

Level	Manifestation	Essence	Examples
First	Tools, clothing, shelter	Extension of the body	Hammer extends arm, clothing expands thermoregulation
Second	Language, writing, symbols	Externalization of memory	Knots, writing, books as memory carriers
Third	Machines, automated systems	Substitution of behavior	Automated systems perform repetitive labor
Fourth	AI, silicon cortex	Externalization of thought	Silicon systems assist thinking, integration, extension

Biological significance: Perimpletion enables humans to break through the speed limit of biological evolution. Biological evolution takes millions of years; cultural evolution takes only a few generations. Biological memory is confined to an individual's lifespan; cultural memory can span millennia. The lynx paw in Arseniev's pocket carries a people's suffering memory; the preprint of "The Sentient Principle" in our database carries the crystallization of your thought. These externalized traces allow an individual's "sensation-behavior loop" to merge into larger loops—civilizational, historical, intergenerational.

Relation to "trace and re-sensing": Perimpletion is the extension of "trace and re-sensing" to the cultural level. Notches on trees, knotted cord systems, written words, database code—all are traces actively created by humans. When later generations read these traces, they engage in cultural "re-sensing": not simply extracting information, but in "the remembered present," integrating the thoughts of predecessors with their own understanding in real-time to generate new meaning.

Empirical cases: The various memory tools analyzed by Vygotsky—tree notches, knotted cords, lynx paws—are early forms of perimpletion. Though simple, they reveal its essence: *creating a wholly new structure of memory as a psychological process through external tool-symbols.* Today's AI and silicon cortex are merely contemporary continuations of this process.

3 From Shadow to Substance: The Sentient Principle Integrates a Continuum of Sentience Across All Life

3.1 Basal Life: Living Fossils Where Innateness is Physics

Taking slime moulds as an example, their "intelligent" behaviors can be fully explained by "innate presuppositions + physicochemical mechanisms + threshold flux":

- **Habituation**: Diminished aversion to salt arises from increased intracellular sodium concentration, eliminating the internal-external difference. This is a direct result of material retention, requiring no "learning."
- **Network optimization**: Maze-solving is hydrodynamic positive feedback,

a physical necessity.

- **Social recognition**: Differential responses to conspecific ECS traces are an innate recognition system, genetically encoded.
- **Post-fusion mitochondrial DNA elimination**: "Value-based selection" controlled by a nuclear gene locus, a one-time ruling.

Slime moulds possess abundant "value-based selection" but lack "iterative" capacity, thus halting at "flux" without genuine "consolidation" learning. This is the ultimate expression of "innateness priority": achieving optimal adaptation with the most economical physicochemical mechanisms.

Why "Sensitization" and "Associative Learning" Are Unnecessary: The Biological Significance of Innateness Priority

The deep reason why basal life forms like slime moulds do not require "sensitization" or "associative learning" lies in the triple biological significance of "innateness priority":

More effective: For organisms living in relatively stable ecological niches, evolutionarily preset innate strategies are optimal solutions. Slime mould chemotaxis completes in seconds to minutes, requiring no "learning"; habituation to salt is achieved through material retention, needing no complex neural computation. These innate capacities fulfill critical survival needs with minimal cost, zero latency, and guaranteed effectiveness. Evolution selects "good enough" strategies, not "the more complex the better."

More direct: In innate mechanisms, there is no intermediary between stimulus and response. Sensors directly couple to effectors; evolutionarily preset value baselines directly endow stimuli meaning; responses execute immediately. Slime mould habituation to salt is a direct result of "material retention"—salt inside the cell, memory present; salt excreted, memory lost. This is not "learning" but a direct physicochemical consequence. This directness ensures response speed and reliability, avoiding delays and errors that complex intermediaries might introduce.

More important: Any acquired adjustment is a fine-tuning within the innate framework and cannot transcend the fundamental constraints of the innate baseline. Slime moulds can habituate to quinine but can never learn to “like” quinine—the negative value of defensive tension is innately locked; they can adjust their tolerance threshold to salt but can never change the fundamental evaluation that “salt is harmful.” Innateness is the “operating system,” the acquired is merely an “application” running on this system. For basal life, the stability and reliability of the operating system are far more important than the richness and diversity of applications.

This is the evolutionary logic of “innateness priority”: *The highest form of adaptation is adaptation that requires no learning; the most successful evolution is evolution that changes by remaining unchanged.* Basal life forms like slime moulds have proven the superiority of their design over billions of years; they need no “sensitization” to remain alert to every new stimulus, nor “associative learning” to establish complex symbolic associations—because in their ecological niches, the truly important information is already firmly encoded through innate presuppositions, while secondary information is not worth expending energy to learn.

3.2 Animal Cognition: The Iterative Revolution of Nervous Systems

While the cognitive capacities of neural animals and humans are well-established and not disputed in current debates, we briefly outline how the Sentient Principle accommodates these cases to demonstrate its full explanatory range.

The emergence of nervous systems made “value-dependent selection” possible. Neurons, as specialized coordination units, achieve iterative consolidation of experience through synaptic plasticity. This corresponds to the “specialized coordination” and “integrated coordination” stages in “Early Transitions in the Evolution of Cognition.” Animals thereby acquire abilities such as conditioning and operant learning, where iterative depth and memory depth jointly determine learning complexity.

3.3 Human Cognition: Infinite Recursion Created by Perimpletion

Through cultural perimpletion—language, writing, technology—humans extend memory carriers from biological synapses to the external world, enabling iteration to transcend individual lifespans and achieve intergenerational recursion. Advanced cognitive forms such as science, art, and philosophy are precisely the infinite unfolding of "value-dependent selection" at the civilizational level.

The uniqueness of human cognition lies in our ability not only to sense the external world and our own internal states but also to make "sensation itself" an object of sensation—i.e., the "sensation" of one's own neural activity, and regarding neural activity itself as a kind of internal "behavior." This metacognitive ability enables us to reflect, question, debate, construct theories, formulate hypotheses, and critically verify. It is precisely this ability that allows us all to discuss issues like "basal cognition" here.

However, even "consciousness" itself is not a discrete presence-or-absence attribute but a continuous spectrum. Just as sentience ranges from vague to clear, consciousness manifests as a continuous transition from clear consciousness, marginal consciousness, subconscious, unconscious, to non-conscious. Dream's vague imagery, automated skill execution, repressed subconscious impulses, the unconscious state of deep sleep, and the non-conscious activities of purely physiological processes—all are different positions on this continuum, not sharply separated categories.

This means that when we say certain life forms "lack consciousness," we are not consigning them to the dark abyss of "mere machines," but acknowledging that they may reside at the vague end of the sentience spectrum—that primitive, non-reflective yet genuinely existing distinction between "good" and "bad." This aligns perfectly with the Sentient Principle: all life shares a common foundation of sentience, differing only in clarity, complexity, and reflectivity due to evolutionary levels.

4 The Sentient Principle's Response to Current Debates

4.1 Transcending the "Basal Cognition" Debate: The Case of *Physarum polycephalum*

The debate over whether *Physarum polycephalum* possesses "learning," “memory,” or “decision-making” abilities epitomizes current “basal cognition” research. Proponents, citing behaviors like maze-solving, network optimization, and habituation, extend cognitive terminology to non-neural organisms; opponents insist these behaviors can be reduced to physicochemical mechanisms. The Sentient Principle offers a third path: acknowledging the complexity and adaptability of slime mould behaviors but understanding them as expressions of “innate presuppositions + physicochemical mechanisms + threshold flux,” without needing categorizing them as “learning” or “memory.” Slime mould habituation to salt is a direct result of material retention; network optimization is hydrodynamic positive feedback; social recognition is innate genetic encoding—all are rudimentary forms of the “sensation-behavior loop” at the root of the evolutionary tree. Their greatness lies precisely in achieving optimal adaptation with the most economical physical mechanisms, not in “learning” like animals.

4.2 Supplementing the “Basal Cognition” and “Minimal Cognition” Frameworks

The “basal cognition” framework attempts to understand cognition from evolutionary roots but often still references animal paradigms. The Sentient Principle, with the “sensation-behavior loop” as a more fundamental unit, avoids the twin pitfalls of definitional over-extension and over-restriction. It can accommodate both bacterial chemotactic adaptation and explain human mental activity, forming a genuine continuum.

4.3 Stance on the “Consciousness” Debate

Taiz et al. (2019) correctly point out that plants lack the neural complexity required for consciousness but may conflate sentience with consciousness—a distinction the Sentient Principle seeks to clarify. The Sentient Principle distinguishes between them: *sentience* is an inevitable concomitant phenomenon of life maintaining its own existence, the root of the evolutionary tree, the very substance that casts all shadows. *Consciousness* can be understood as a bright line emerging on the sentience spectrum—but this “bright line” itself, as the object of our observation and discussion, remains a phenomenal “shadow,” a description of some state of the substance (the sentient system), not the substance itself. Consciousness appears only in a small number of groups, but its mode of existence shares the same sentient foundation as all life.

More importantly, consciousness itself is also a continuum. Even within humans, from clear waking consciousness to the vague imagery of dreams, from highly focused "flow" to automated skill execution, from repressed subconscious to purely physiological processes inaccessible to consciousness—these are not sharply divisions of "presence" or "absence" but continuously transitioning gradients. This continuity aligns consistently with the Sentient Principle: sentience ranges from vague to clear, consciousness from periphery to focus, all different expressions on the same foundation.

5 An Open Methodology: How to Study Living Substance

The Sentient Principle is not only a theoretical framework but also a guide for research methodology. It demands a fundamental shift in research perspective: *from asking "does life have the abilities we define," to asking "how does life, in its own unique way, sense the world and maintain its existence."* This shift, implemented in concrete research practices, manifests as three interrelated methodological principles.

First, prioritize biological significance. Research should start from the survival needs of the organism, not from the researcher's toolbox. This means, before designing and interpreting any experiment, first ask: what challenges does this life truly need to confront in its natural ecological niche? How do its "sensation-behavior loops" serve the three basic tensions—defensive (maintaining boundary integrity), aggressive (acquiring energy resources), empathetic (sustaining rhythm and race)? Only by anchoring on these fundamental questions can we avoid mechanically applying concepts developed in animal paradigms (like "learning," "memory," "decision-making") to other life forms. Slime mould habituation to salt, viewed through the lens of animal learning, might be misread as "non-associative learning"; but viewed through the lens of prioritizing biological significance, it is essentially a threshold flux caused by material retention, an emergency strategy for temporarily adjusting sensory thresholds in unavoidable environments. The superiority of one interpretation over another lies not in which is more "objective," but in which is closer to the life's own situation.

Second, embrace all empirical means, but exercise interpretive restraint. Extreme laboratory studies—whether dogs on Pavlov's stand or slime moulds in uniformly saline environments—have irreplaceable value. They reveal response mechanisms under extreme conditions, allowing us a glimpse into the boundaries of innate presuppositions and the limits of flux. Without such studies, we might never know that slime moulds can achieve habituation through material uptake, nor how animals recalibrate expectations when escape is impossible. However, the crucial point is to clearly recognize that these studies create "laboratory situations," not "ecological archetypes." Misinterpreting emergency mechanisms under extreme conditions as everyday strategies is the root of many current controversies. Researchers have a responsibility to clearly distinguish between them and to frankly acknowledge in their conclusions the differences between experimental situations and natural ecology.

Third, seek cross-level evidence integration. Living substance is multi-layered—from molecules, cells, to tissues, individuals, each level's activities intertwine with others. Research advocated by the Sentient Principle should not remain at a single level but pursue integration of evidence across levels. Slime mould habituation research provides a model: behavioral observation shows diminished aversion to salt; physiological measurements reveal increased intracellular sodium concentration (10 times higher in habituated individuals); manipulative experiments demonstrate that forced salt absorption induces habituation, while excretion recovers behavior. These four levels of evidence mutually confirm each other, together revealing the core mechanism of "material retention." Similarly, in animal studies, combining behavioral observation, neural recording, and molecular interventions allows a more comprehensive understanding of how "value-dependent selection" is implemented. Cross-level integration is not simple data accumulation but approaching the true operation of living substance through mutual constraint and complementation of evidence from different levels.

These three principles collectively point to a fundamental stance: *Research methods should serve the understanding of life, not make life serve the convenience of research methods.* Prioritizing biological significance ensures the starting point is correct; openness to all empirical means ensures the possibilities are sufficient; cross-level evidence integration ensures the conclusions are reliable. Their combination enables us to utilize the sophisticated tools of modern science without losing ourselves in the tools, always keeping our gaze fixed on the substance that casts all shadows—the living, sentient being itself.

6 Conclusion: Returning to Life Itself

This intellectual path ultimately reveals a profound continuum: from bacterial chemotactic adaptation to slime mould material retention; from animal neural iteration to human metacognitive reflection; from the most vague primordial sentience to the clearest conscious experience—all life senses the world and maintains its existence in its own unique way. They are all expressions of the "sensation-behavior loop" at different levels of organization, and all share the same sentient foundation.

However, this position may be met with criticism: "The term 'sensation' itself is vague; using it to describe all life merely replaces one vague concept with another." To this, we respond: *"Sensation" is not a discrete property, but a continuous spectrum*—a claim grounded not only in evolutionary comparisons across species but also in the immediately accessible inner experience of human beings themselves. Within a single human individual, sensation spans from the vivid qualia of focused awareness, through the blurred imagery of dreams, to the minimal differential responsiveness maintained during deep anesthesia—forming a seamless gradient. No one can draw a clear boundary within this continuum and declare, "on this side there is sensation, on that side there is none." If one accepts—as one must—that sensation admits of degrees within the human individual, then the question is no longer whether other life forms "possess" sensation, but where they are located on the *very same continuum that we ourselves inhabit*. To deny this continuity across species requires explaining why a continuum that is unbroken within the human individual should suddenly fracture at the boundary of the species—a claim for which evolutionary biology offers no support. Therefore, when we say that all life possesses "sensation," we are not anthropomorphically projecting human experience onto other beings; rather, we are pointing out that *all life shares a common sentient foundation, differing only in clarity, complexity, and reflectivity across evolutionary levels*. This stance both respects the particularity of subjective experience and transcends the distortions of anthropocentrism.

It is precisely on the basis of this understanding that we can more deeply grasp human uniqueness. Through the “re-sensing” of our own neural activity, we are able to transform this sentience into reflection, dialogue, and creation. It is this very capacity that allows us to propose the “Sentient Principle,” to clarify concepts amidst debates, and ultimately to return to life itself.

“They can eat light, isn't that enough?” This rhetorical question should become the motto for our study of all life: before asking “does it have consciousness” or “can it learn,” first marvel at what it “can do”—those remarkable capacities forever beyond our reach, yet which underpin the entire ecosystem. And in our marveling, we are already using our human sentience to resonate with the sentience of other life. This is what it truly means to be sentient.

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