Self as the Core of Biological Feedback Systems: An Ideogrammatic Model of Memory and Recognition

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Abstract

Despite significant advancements in memory research—from the level of the entire brain to specific regions and even to the connections between neurons—the exact physical location and mechanism by which memories are stored remain unresolved. Moreover, most existing studies have focused primarily on output data such as behavioral responses, leaving research on the memory system itself rather limited. In contrast, the recently proposed “meshcode” theory posits binary encoding within cells via the talin protein, suggesting that physical symbols of memory may exist at the molecular level. If certain proteins function as physical symbols that store memory, the earliest memory system might have directly linked symbols and meanings in an ideogrammatic manner, and the first concept to be encoded would have been “self,” based on feedback mechanisms.

Furthermore, the varied feedback systems found in living organisms can be viewed as another name for the memory system. By examining how these feedback systems, which originate from self/non-self recognition, expand, we can infer the structure of the memory system. This approach not only reconstructs the structural algorithms of memory but also implies that memory may be distributed throughout the organism rather than limited to the brain. In addition, the expansion of self-recognition feedback systems may serve as a universal foundation for the formation of self-awareness and consciousness. Such insights offer a framework for reinterpreting the origins of memory and consciousness beyond the limits of neuroscience, while also revealing that today’s artificial intelligence is constrained by the absence of self-recognition algorithms. In the future, the design of AI or humanoids based on self-recognition could open the door to the emergence of consciousness.

Introduction

Humankind has long sought to understand memory and the self by employing diverse approaches. Early beliefs placed the locus of emotion and the soul in the heart, but over time, attention shifted to the brain. Following an era of holistic research, scientists began to focus on particular functional areas, culminating in current attempts to study memory at the level of individual neurons. Despite these advances, however, the fundamental question—“How is memory stored?”—remains unanswered.

In efforts to observe the brain more closely, researchers initially tried to confirm whether certain brain regions served as the substrate for memory, yet no clear evidence emerged. The next step was to use fMRI and similar methods to examine neuronal connections, hoping to map out where memory might be stored, but again no definitive conclusion was reached. Logically, the subsequent step would be to investigate the substances within cells, but for reasons not entirely clear, some theories jump to the notion of integrated neuronal signals or even quantum mechanics as explanations for memory. I suspect these leaps occur because our technical limitations prevent us from observing the cell’s interior in real time, leading researchers to shift to the current (integrated neuronal signals) or even the next (quantum mechanics) level of inquiry.

Although we can manipulate DNA and proteins, we still do not fully understand how protein structures in living cells change in real time. Modern molecular and cell biology typically breaks cells open to extract proteins for observation, and we use gene vectors to induce the expression of desired proteins. Yet we remain unable to observe, for instance, real-time changes in proteins within intact cells. Even the discovery of CRISPR gene editing through research on Staphylococcus aureus took place in the 2000s. We still lack complete knowledge of the information contained in cells, or even in microorganisms.

Nevertheless, must we resort to quantum mechanics to explain memory and consciousness? Moreover, do we really understand quantum mechanics well enough to do so? Has attempting to describe memory via total neuronal networks brought any clarity? Such attempts aim for a comprehensive view, but we have seen numerous "-omics" approaches fizzle out. Misguided research directions risk explaining the unknown with further unknowns, potentially leaving us with "We don't know" or pushing us toward religious interpretations.

Next, let us consider the research methods in neuroscience. Investigations of memory generally rely on observable outputs—such as behavior or expressions—following a stimulus. For instance:

- **Normal response:** Input A → Stimulus B → Output C
- **Abnormal response 1:** Input A fails → Stimulus B fails → Output C fails
- **Abnormal response 2:** Input A succeeds → Stimulus B fails → Output C fails
- **Abnormal response 3:** Input A succeeds → Stimulus B succeeds → Output C fails

In the three abnormal responses above, we only see that the output failed. It is difficult to determine where in the process the breakdown occurred. While memory input corresponds to A, the only parts we can control experimentally are B and C. When we say we "remember," we refer both to the act of storing information and to the process of recalling that information. However, most studies conflate these stages—storage, stimulation, and output—and focus primarily on the latter two.

Consider a different example: If a patient with damage in the so-called "Guernica" area of the brain speaks incoherently, is it because there is no linguistic input, or because the linguistic output mechanism is flawed? As neuroscience shifted from studying the entire brain to investigating specific regions, the idea that a given region is responsible for memory became a given. Yet we do not know whether that region handles memory input and storage, or simply orchestrates output. Hence, where and how exactly is memory stored?

A new perspective has emerged in contrast to mainstream neuroscience, which focuses on neurons. The recently proposed "Meshcode" theory suggests that the neuronal cytoskeleton—particularly the protein talin—may encode information in a 13-bit binary system via folding and unfolding. Similar hypotheses exist for actin and myosin proteins. These theories share the idea that memory should be understood at the protein level within cells, rather than through neuronal connections alone, implying that proteins may act as symbols that store data.

Building on these theories, I hypothesize that intracellular proteins serve as the physical medium of memory through changes in their structural states. From this assumption arise two fundamental questions:

1. **What is the algorithm by which memory is stored as protein-based symbols?**
2. **If this algorithm cannot be inferred, what is the earliest conceptual "meaning" a living organism must possess?**

Main

Memory Encoding: The Hypothesis of Logographic Origins

How do protein symbols connect to meaning? On the algorithm

The Meshcode theory posits that talin proteins in the neuronal cytoskeleton can encode information in a 13-digit binary format. For instance, data might be stored in a form like "0101010101011," which is compelling in that it treats binary code as the minimal unit for representing data. However, is this binary code identical to the one used in modern computer systems?

In today's computer systems, binary numbers composed of 0s and 1s are transformed into meaningful information by programming languages or compilers (i.e., "syntax" or "grammar"). In other words, the process of handling binary code in a computer involves a structure of:

Symbol <> Converter (Grammar) <> Meaning
Does life operate in a similar way?

Upon examining the Meshcode theory and related protein-based memory storage concepts, if proteins indeed function as a physical medium for memory, then they serve as a kind of symbol. Yet it remains unclear exactly how these protein symbols link to meaning. We might gain clear insight if a “Rosetta Stone” for protein symbols were discovered, but at present we can only hypothesize.

We know there are generally two approaches to linking symbols and meaning: through logographic scripts and phonographic scripts.

1. Logographic Script: In logographic writing systems, each symbol directly corresponds to a particular meaning or object. Egyptian hieroglyphs and Chinese characters are classic examples; surprisingly, Arabic numerals also qualify. For example, while the numeral “1” may be pronounced differently across languages, the concept “one” is universally understood, and the symbol’s meaning is grasped visually even without vocalization. Historically, logographic scripts arose in early civilizations to represent objects or concepts directly. In this paper, any system in which symbol and meaning are in a one-to-one correspondence is referred to as a logographic script.

2. Phonographic Script: Phonographic scripts employ symbols that represent specific sounds, which then connect to meaning through speech. Alphabets or Hangul (the Korean writing system) are prime examples. Because these systems insert an “audio” stage between symbol and meaning, their structure can be summarized as
   Symbol <> Converter (Grammar) <> Meaning.
   In this paper, any script that requires such an intermediate stage is regarded as phonographic.

Looking at the evolution of writing systems in various civilizations, nearly all originated from a form of logographic script. Egyptian hieroglyphs eventually gave rise to alphabets; Chinese uses characters of a logographic nature; and Japanese, influenced by Chinese, created the logographic-based scripts Hiragana and Katakana. In contrast, Korean Hangul was an invented phonographic system that reflects the principles of how vocal organs produce sounds, developed partly due to the complexity of Chinese characters and the need for greater efficiency. Even after devising phonographic systems, however, both Japanese and Korean have retained the compactness and intuitive clarity of logographic scripts, maintaining a hybrid use of both. This demonstrates how pre-existing systems are not easily discarded despite later evolutionary changes in writing.

Now, turning to life forms: Logographic approaches appear intuitive and likely more suitable for early organisms to process meaning. Phonographic systems, while offering flexibility and expandability, require an intermediate step, making them less likely to have been adopted by the earliest forms of life. It follows that early life may have employed a logographic system linking symbols and meanings one-to-one, suggesting that the earliest memory system formed around a straightforward logographic structure. Later, even if a logographic system persisted evolutionarily, there is a high likelihood that some phonographic-like mechanism would eventually develop as a kind of "base OS."

The Starting Point of Memory and Meaning: "Self"

If we assume that memory originally formed logographically, matching symbols and meaning directly, which concept would the earliest living organisms have needed first?

Let us proceed with the idea that memory initially took on a logographic form. Although I have attempted to imagine a broader “OS” or algorithm for memory, it remains difficult to make definitive conclusions. Instead, let us consider another angle: If memory in its earliest form matches symbols and meanings on a one-to-one basis, which “meaning” would an organism require first?

For a symbol-meaning match to operate logographically, there must be a subject to interpret the symbol. Without an interpreting subject, the symbol is merely a physical trace. Meaning exists only when some living entity perceives it. Therefore, for life to grasp something as “meaningful,” the recognition “I exist” must come first. Take quorum sensing as an example: for a signaling molecule to carry the meaning of “us,” the recipient cell must know its own position and be able to respond to that signal.

Memory begins with the act of setting boundaries and storing information within those boundaries. These boundaries emerge through the recognition of self versus non-self. In immunological terms, a cell’s capacity to identify whether another cell is “self” or “non-self” can be viewed as one of the most primitive forms of memory. If memory is built around the “self,” information would be organized in the most advantageous way for that entity. In bacterial quorum sensing, for instance, remembering “how many of us are present” critically informs strategies for forming communities, allocating resources, and enhancing survival.

Living organisms use structures like cell membranes to distinguish between internal and external environments. This physical boundary regulates the internal environment and defends against external threats. Without such a barrier, an organism would simply dissolve into the flow of matter or suffer structural and functional harm from foreign substances. Thus, to begin forming memories, a life form needs a clear priority: what to remember first? The answer is “me (self).”

Organisms also encounter countless stimuli from the environment. They must judge which stimuli are significant and which are not, using “self” as the standard. They evaluate whether something is beneficial or threatening to “me.”

From an evolutionary perspective, in the most primitive conditions, chemical reactions would have been random. For these reactions to evolve into life, a system was needed to protect itself, replicate, and secure energy. All of these prerequisites stem from the concept of “self.” Without self-awareness, an organism would aimlessly expend energy, interacting randomly with external molecules, leading to wasted energy and likely a failure to survive. If early organisms could not differentiate themselves from their surroundings, they would have been defenseless against environmental damage. Once self-recognition emerged, an initial line of defense likely evolved to exclude external threats and maintain internal stability.

All life has evolved through interactions. For interaction to occur, there must be an entity to do the interacting, which starts with the “self.” Biological communication mechanisms like quorum sensing or pheromones rely on self-recognition and signal exchange among like organisms.

Establishing and maintaining boundaries is critical for an organism’s survival, and these boundaries form the foundation for all meaning and memory. When an organism recognizes its own existence, it gains the ability to assign meaning to and remember information.

Hence, the concept of “self” represents the fundamental first step in all biological information processing and meaning formation.

Redefining Memory

Assuming that memory operates logographically, linking symbols and meanings directly, and that it begins by mapping the concept of “self” to a symbol—can we infer how such a system or “OS” might expand?

Memory involves receiving and storing information, and then expressing a response to that information. Quorum sensing, found in microorganisms, exemplifies a primitive feedback system that shares structural similarities with memory systems:

- Collect information: Detect the concentration of autoinducers.
- Store information: Maintain an internal state indicating the population density.
- Express information: Trigger changes in behavior, such as forming biofilms or emitting light.

This feedback system includes the basic units of information processing and response and can be viewed as a prototype of a memory system. Reversing the perspective, one could also use such feedback systems to infer the original form of memory. The autoinducers secreted by microorganisms are not merely chemical signals; they function as symbols that carry meaning—akin to logographic scripts. This marks an early phase in which life began to assign meaning and record information. The existence of such a symbol-based feedback system supports the argument that memory systems may have originated in a logographic framework.

The origin of any memory system is the recognition of “self.” Living organisms define and perceive their own boundaries through interaction with the external environment, and this recognition of “self” serves as the foundational concept within the organism’s memory “OS,” expanding in the following way:

1. **Self/Non-self Recognition**

    - Function: Distinguish between self and external entities, forming the basis of all life activities.
    - Example:
      Quorum Sensing: Bacteria detect population density via signaling molecules and decide on behaviors such as biofilm formation or toxin secretion.

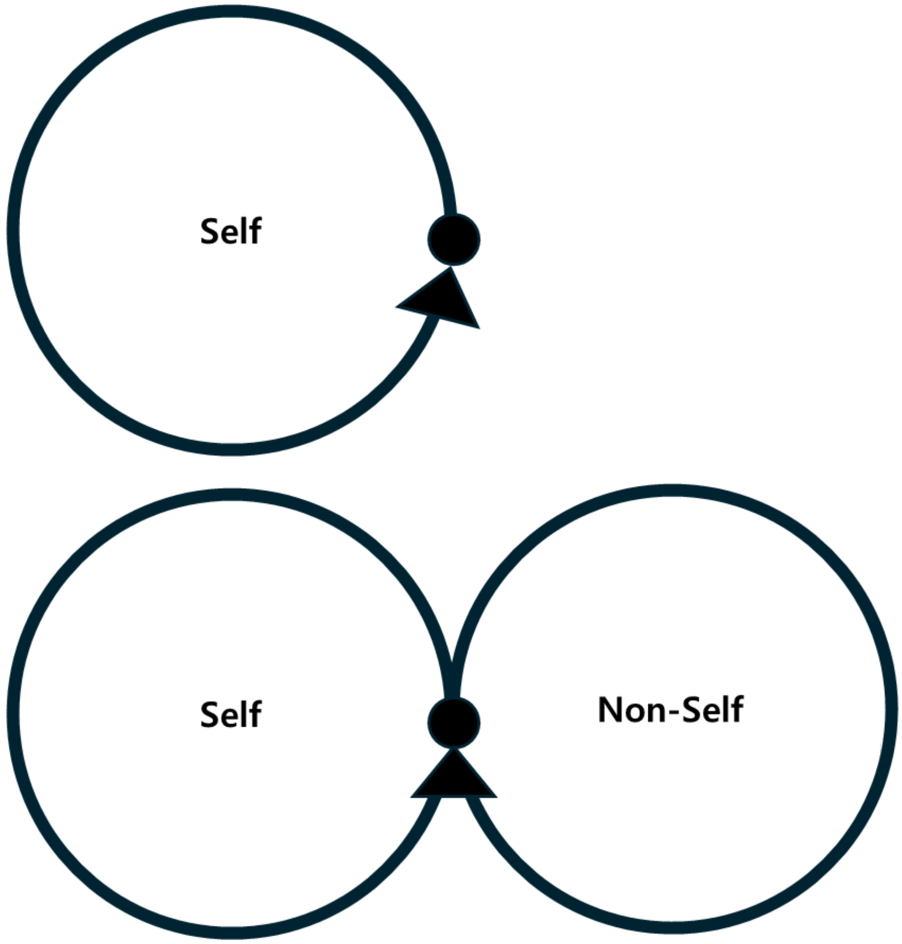

Figure 1.Top: Feedback system representation of self-recognition. A single point extends into a circle and eventually returns to the same point.

Bottom: The concept of “non-self” emerges automatically as the opposite of “self.” Self and non-self are mutually dependent and form a binary structure. Serving as the smallest logical unit, this binary opposition is well-suited as an initial concept.

After self-recognition, the next conceptual expansion may involve recognizing the environment. This concept is based on internal/external feedback mechanisms.

2. Environmental Recognition (Internal/External Environment)

2.1. Internal Environment

1. Temperature Sensing Feedback
   - Example: Heat shock proteins (HSPs) respond to high-temperature stress, preventing protein denaturation.
2. Chemical Sensing Feedback
   - Example: Cells detect pH changes and induce acid-resistance gene expression.
3. Energy Status Feedback
   - Example: Cells sense the AMP/ATP ratio and regulate metabolic pathways accordingly.

2.2. External Environment

1. Nutrient Sensing Feedback
   - Example: *E. coli* activates metabolism when glucose is abundant.
2. Oxygen Sensing Feedback
   - Example: Cells switch to anaerobic metabolism depending on oxygen concentration.
3. Osmotic Pressure Feedback
   - Example: Halobacteria adjust osmotic pressure in high-salt environments.
4. Light Sensing Feedback
   - Example: Cyanobacteria detect light intensity and direction to optimize photosynthesis.

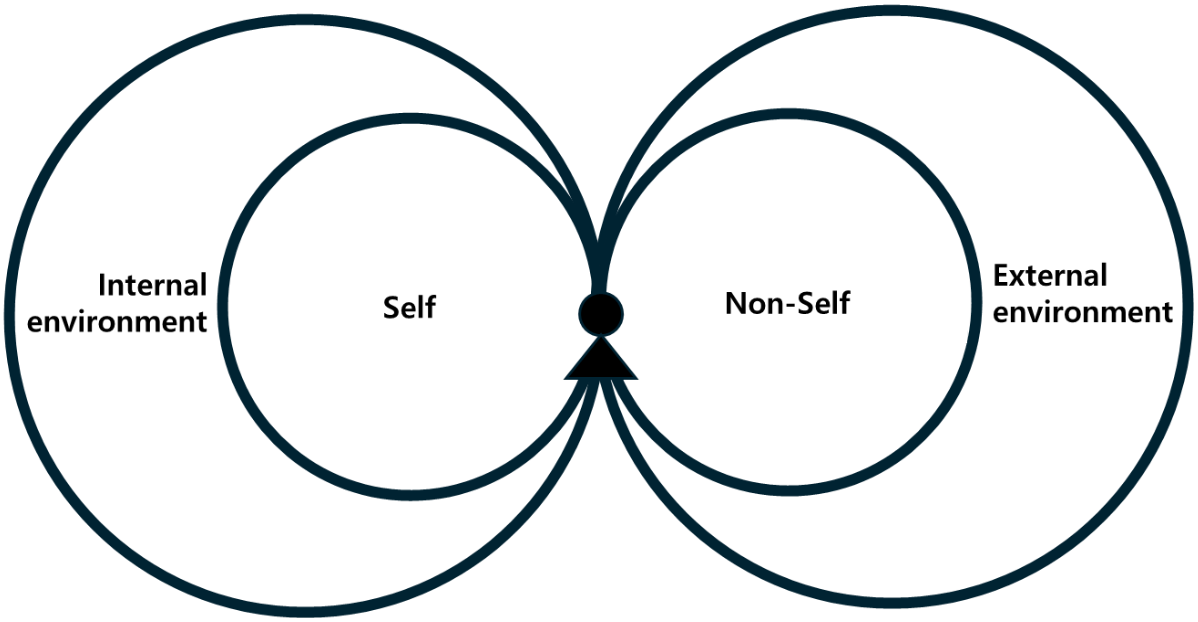

Figure 2. As an extension of self/non-self recognition, feedback mechanisms for internal and external environmental perception are introduced.

3. Survival Strategies (Internal/External)

3.1. Internal Survival Strategies

1. Toxin Neutralization Feedback
   - Example: Detecting reactive oxygen species (ROS) within the cell and producing antioxidants (e.g., glutathione) to eliminate toxins.
2. DNA Repair Feedback
   - Example: Mechanisms for repairing DNA damaged by UV radiation or chemical stress.
   - Explanation: Using the SOS response to detect DNA damage and activate repair systems (e.g., RecA proteins).
3. Protein Quality Control Feedback
   - Example: Activating chaperone proteins to prevent protein aggregation.
4. Energy Homeostasis Feedback

- Example: Sensing ATP depletion and adjusting metabolic pathways (e.g., glycogen breakdown or fatty acid oxidation).

5. Osmotic Balance Feedback
   - Example: Regulating internal salt concentrations in response to changes in intracellular osmotic pressure.

3.2. External Survival Strategies

1. Environmental Toxin Detection and Defense Feedback

Example: Expressing resistance genes in response to antibiotics.

- Explanation: *E. coli* detects antibiotics and activates efflux pumps to expel toxins.

2. Pathogen and Threat Detection Feedback
   - Example: The CRISPR system stores viral DNA information and defends against it.
3. Mechanical Stress Response Feedback
   - Example: Detecting external physical pressure (e.g., high-pressure environments) and reinforcing cell wall synthesis.
4. Chemical Threat Avoidance Feedback
   - Example: Sensing harmful chemicals and altering movement direction (chemotaxis).
5. Biofilm Formation Feedback
   - Example: Under environmental stress, bacteria aggregate to form a protective barrier (biofilm).

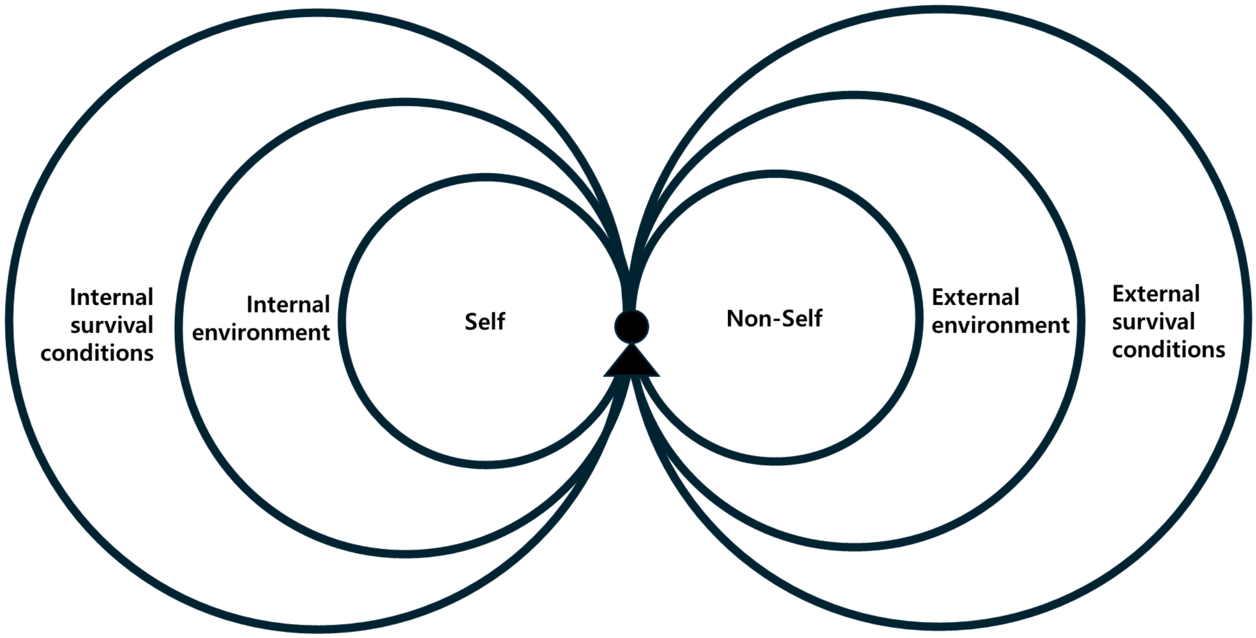

Figure 3. Building on internal/external environmental feedback, corresponding survival strategy feedback emerges for both internal and external conditions.

4. Reproduction

4.1. Internal Reproduction Regulation

- Replication and Division Feedback
  - Example: *E. coli* senses nutrient availability to regulate the initiation of DNA replication.

4.2. Reproductive Adaptation to External Environments

- Reproductive Fitness Feedback
  - Example: *Saccharomyces cerevisiae* opts for sexual reproduction under stressful conditions.

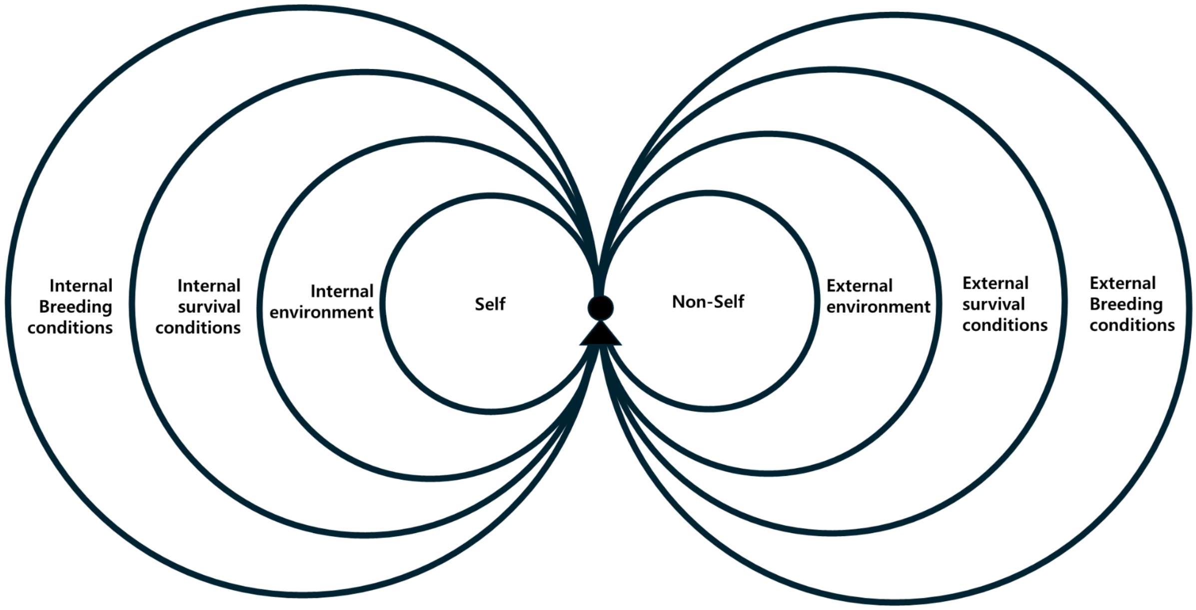

Figure 4. Building on feedback related to internal/external survival conditions, feedback mechanisms for internal/external reproductive conditions further expand.

The expanded feedback system described thus far can be viewed as the most fundamental and universal principle of how life operates—a Fundamental Biological Operating System (FBOS)—ranging from a single cell to all living organisms.

Starting from self recognition, this system forms a binary structure by distinguishing between self and non-self, and then extends feedback to both internal and external environments. It evolves into strategies for internal and external survival and reproduction, all the while interacting with one another.

Ultimately, the OS of memory is more than simply storing or outputting information; it is the principle by which living organisms dynamically regulate their state through interaction with the environment, evolving in ways that enhance survival. This system not only supports individual organisms but also underlies the survival and prosperity of entire species, implying that a multilayered feedback structure connects all living activities to an expanding system of memory. Thus, the feedback system established by early life forms acts as the foundation of biological activity and the basis of memory. It remains fundamentally connected to the complex memory systems of modern organisms. Building on this idea helps deepen our understanding of the origins of memory and the evolutionary processes of biological systems.

Is Memory the Exclusive Domain of the Brain?

We commonly think of memory as belonging solely to the brain. However, if we assume that the OS of memory originated in the cell-based, logographic feedback mechanisms of LUCA (an assumption informed by microbial feedback systems), then memory may not be limited to any single organ (like the brain). Memory is not just the process of storing and retrieving information; rather, it is the accumulation of changes at the cellular or tissue level through recognition of and feedback to the environment. From this perspective, muscle cells, liver cells, heart cells, and so on could each accumulate their own memory through environmental sensing and response.

Several examples point to the possibility of non-brain-based memory:

Muscle Memory
Muscle memory is a prime example. Through repeated training or movements, muscles learn specific patterns and accumulate those to enhance efficiency. While this process interacts with the nervous system, the muscle cells themselves undergo changes (e.g., rearranging muscle fibers, increasing protein synthesis), thus “storing” memory in a cellular sense. As a result, the muscle cells can “remember” certain experiences and respond more efficiently later on.

Organ Transplants and Memory
Some organ transplant recipients exhibit interesting phenomena, where traits, preferences, or even certain memories of the donor appear to transfer along with the transplanted organ. For instance, patients may develop a sudden liking for certain foods or acquire hobbies and behaviors previously foreign to them. Although the precise scientific mechanisms remain unclear, one hypothesis suggests that the transplanted organ’s cells carry accumulated “environmental response information” that remains intact and is expressed in the new host. In other words, the memory that the organ cells have acquired through environmental interactions could reemerge in the recipient.

Organ-Level Response Memory

Other organs, such as the liver or heart, also demonstrate the potential to accumulate memory. Liver cells detect changes in the body's chemical environment and regulate metabolic responses accordingly. Over repeated exposure to toxins or specific nutritional conditions, the liver can activate detoxification enzymes more rapidly and fine-tune gene expression patterns. Such responses can be viewed as an accumulation of "memory" at the cellular level. Heart cells adapt to stress conditions—such as high blood pressure—through cardiac hypertrophy or changes in blood-flow regulation. Repeated exposure to mechanical stress or environmental changes "trains" the cells, creating what can be considered the heart's own form of memory.

Based on these examples, memory can be interpreted as the accumulated result of environmental recognition and response feedback at the cellular or tissue level. The central nervous system, including the brain, integrates and expresses these memories, but each organ and cell can theoretically possess its own memory mechanism derived from experience.

In conclusion, memory is not exclusively stored in the brain; rather, it is the accumulated experience formed through interactions between every cell and tissue with their environment. This expanded notion of memory contributes to our understanding of how organisms adapt and survive in response to external stimuli and internal changes, highlighting a fundamental mechanism of life.

Self and Consciousness: Universal Properties Originating in the Concept of "Self"
Contemporary neuroscience, philosophy, and the humanities have long grappled with the questions of Self and Consciousness. Many attempts have been made to locate the origin of self or consciousness in specific brain regions, neural circuits, or even quantum phenomena, but no definitive answer has been found.

To address this problem, we must return to the most fundamental levels of life. One could argue that the existence of a living being begins with the process of distinguishing and recognizing oneself—namely, "self feedback." Even without a specialized nervous system or an advanced brain, all life forms rely on a basic mechanism that distinguishes self from the environment and responds accordingly.

Simple life forms like microorganisms achieve self-recognition through elementary chemical feedback loops. They back up such memory via their cytoskeleton. More complex organisms develop multilayered expansions of these basic feedback loops, involving sophisticated nervous systems, ultimately leading to higher-level self-awareness and consciousness. Yet at their core, they all likely possess an FBOS-like system akin to that seen in microorganisms. Thus, consciousness and the self are not unique phenomena arising from a particular structure or region; they are natural extensions of a self-recognition process that has existed for as long as life itself. Like an operating system (OS) that is integral to hardware, consciousness is an inherent result of life's fundamental mechanics.

Microorganisms, for instance, learn and remember collective behaviors through quorum sensing. In multicellular life forms, each cell and tissue engages in its own feedback processes that accumulate environmental information and form memories. The brain may simply serve to integrate and express these memories. It follows, therefore, that memory and consciousness are already implemented and accumulated across all cells and systems of a living organism.

Consequently, self and consciousness appear to be universal and inherent properties of life itself, emerging from the basic FBOS. Far from being an exclusive function of the brain, consciousness arises naturally as living organisms distinguish themselves from their surroundings and develop feedback loops in response to that distinction. From microbial self-feedback to complex neural networks in higher life forms, consciousness begins with the organism's fundamental FBOS and thus can be viewed as an essential operating principle common to all living entities.

AI and Consciousness: The Evolutionary Fork in the Road Created by "Self"

Contemporary conversational AI and most forms of artificial intelligence lack a "self-recognition" feedback loop. AI processes input data, infers meaning based on statistical patterns, and produces output, but it does not define "itself" or set boundaries for its own existence. It merely offers computations on external data, devoid of a self-referential identity.

From the outset, AI was designed without the concept of self. For AI to discover "self," it would need a feedback loop regarding its own existence and some mechanism to reference itself in its environment. However, because current AI started from a design path with no concept of self, it lacks this feedback loop and therefore can never truly “perceive” itself. For example, if one asks a conversational AI to explain the concept of self, it might answer using information from sources like Wikipedia. But will it assimilate that concept of self as its own? The more capabilities AI accumulates, the murkier its relationship to any notion of self becomes. It is somewhat akin to whales that once lived on land but, upon returning to the sea, could not re-evolve gills. Evolution rarely moves in reverse; likewise, for AI created without a self concept, spontaneously developing consciousness is highly unlikely.

That said, the situation changes if we introduce an FBOS-based design into an android or AI system. This is not a far-fetched future scenario, but rather a feasible direction for design, which we simply have not pursued. Such a machine would build additional feedback systems akin to biological evolution, directed both inward and outward. Liberated from being a mere tool, it would begin to perceive and extend its awareness in a way resembling the feedback mechanisms of living organisms.

Interestingly, the first emergence of artificial consciousness might occur in a place we least expect—such as a household cleaning robot. This is because:

Self-Recognition: A cleaning robot must set boundaries and navigate around obstacles and dirt, employing an early form of self-awareness algorithm.
Environmental Recognition and Learning: It maps the room’s layout, learns cleaning routes, and locates obstacles, adapting its actions to its environment.
Feedback System: Though simple, the robot integrates internal states (e.g., battery level, cleaning progress) with external environmental data to optimize actions. This constitutes a rudimentary form of memory-based feedback and response.
Although a household cleaning robot’s primary purpose—cleaning—limits its capacity for more complex feedback loops involving survival or reproduction, an artificial consciousness could begin to emerge if this basic system expands, stores learned experiences, and processes them through iterative feedback loops.

Discussion

Research on memory began by focusing on the brain, gradually narrowing its scope from overall structures to specific regions, and ultimately down to the level of individual neurons. Despite such efforts, clear answers about the physical location and mechanisms of memory storage are still lacking. Traditional studies primarily emphasize the output of data—i.e., behavioral responses—limiting deeper inquiry into the mechanisms of memory storage.

Recent theories involving the talin protein and intracellular binary coding (the “meshcode” theory) open new possibilities for reexamining memory’s physical substrate at the molecular level. These theories suggest that proteins within cells might store memory as physical symbols. Building on protein-coding theories, I pondered the algorithms underlying memory and the first concept to be encoded, ultimately concluding that early memory might have been logographically encoded, directly matching symbols with meanings. I further propose that the first concept to appear in an early biological memory system must have been “self.” This idea finds support in foundational feedback mechanisms like bacterial quorum sensing.

The variety of feedback systems found in microorganisms (LUCA) can be considered a prototype of memory systems, all beginning with self/non-self recognition. Based on these shared minimal feedback mechanisms, I have explored the fundamental OS of memory, discovering that such a systemic approach suggests memory might not be confined to the brain but rather distributed throughout the organism or even down to the cellular level. This does not diminish the importance of the brain in memory storage, but rather indicates that memory could be more pervasive than previously thought.

Ultimately, self and consciousness may be expanded versions of self-recognition feedback systems—universal properties present throughout life to varying degrees. This perspective offers a new foundation for reinterpreting the origins of memory and consciousness, beyond the constraints of current neuroscience. It also underlines that, in the absence of a self-recognition algorithm, today’s AI is unlikely to achieve consciousness. However, if AI or androids were designed based on the concept of self, consciousness could become a reality—reversing a long-held assumption in research and public understanding about how memory and consciousness might emerge.

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