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Article

Cognition and Intelligence in Natural and Artificial Systems

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Abstract

Cognition and intelligence are central concepts in cognitive science, biology, philosophy of mind, and artificial intelligence, yet these disciplines offer conflicting accounts of what each of them means and how the two notions are related. In many accounts the two notions are used interchangeably, while in others intelligence is defined independently of cognitive processes. Dominant human-centered traditions identify cognition with mental processes associated with brains, whereas life-centered perspectives attribute cognitive capacities to all living systems. This article proposes a relational, life-centered, info-computational framework in which cognition is the ongoing autopoietic and sense-making organization of living systems, while intelligence is the degree of competence with which such organization achieves goal-directed problem solving under novelty, perturbation, and uncertainty. Cognition exists in degrees across living systems, from basal cellular sensing and regulation to increasingly complex cognitive organizations, while intelligence correspondingly appears in degrees in the ability to solve cognitive problems. Current artificial systems can exhibit engineered or derivative intelligence and may implement cognition-like functions, but they are not cognitive in the biological sense. The resulting framework clarifies how human-centered, life-centered, computational, and artificial intelligence can be related.

Keywords: cognition; intelligence; info-computation; artificial intelligence; anthropocentrism; biocentrism

1. Introduction

Cognition and intelligence are two central yet still poorly understood concepts across multiple disciplines, including philosophy, psychology, biology, medicine, and artificial intelligence. Despite their ubiquitous use in education, neuroscience, and technology, these concepts remain highly ambiguous. Much of this ambiguity reflects traditional human-centered perspectives that are only partially informed by recent advances in biology, embodied cognition, enactivism, anticipatory systems, philosophy of cognition, and information studies. Many dictionary and encyclopedic sources still perpetuate a narrow anthropocentric understanding, failing to capture the theoretical complexity and empirical breadth of contemporary research.

The conceptual landscape of cognition and intelligence can be organized around two fundamental dividing lines that mark persistent theoretical tensions. The first distinction is between mentalist and embodied cognition frameworks. The second is between human-centered and life-centered approaches. Together, these distinctions provide a useful scaffolding for understanding how different research traditions approach what constitutes cognitive processes and intelligent behavior.

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1.1. Mentalism Versus Embodied Cognition

The mentalist tradition, encompassing both classical philosophy of mind and symbolic information-processing psychology and cognitive science, equates cognition with *conscious thought* or *disembodied symbol manipulation*. Representative definitions reflect this perspective, characterizing cognition as "the use of conscious mental processes" (https://dictionary.cambridge.org/dictionary/english/cognition, accessed on 1 May 2026) or "the broad set of mental processes that relate to acquiring knowledge and understanding through thought, experience, and the senses." (https://en.wikipedia.org/wiki/Cognition, accessed on 1 May 2026). Such approaches focus on abstract mental operations while minimizing the role of physical embodiment in cognitive processes.

Embodied approaches challenge these mentalist assumptions by arguing that cognition in humans emerges through the dynamic interaction of brain, body, and environment, resisting reduction to abstract mental states. As articulated by Foglia & Wilson [1], "Proponents of the view known as 'embodied cognition' emphasize the role of sensory and motor functions in cognition itself. By viewing the mind as grounded in the details of its sensory-motor embodiment, they model cognitive skills as the product of a dynamic interplay between neural and non-neural processes". This perspective reframes cognition as an inherently physical and situated phenomenon rather than an abstract disembodied process.

1.2. Human-Centered Versus Life-Centered Perspectives

Most mainstream accounts, regardless of their position on the mentalism-embodiment spectrum, maintain human-centered assumptions that restrict cognition to human minds or extend it, at most, to other animals possessing nervous systems. This anthropocentric bias limits theoretical scope and empirical investigation to a narrow range of cognitive phenomena associated with complex neural architectures.

The life-centered tradition offers a radical alternative by conceptualizing cognition as intrinsic to life itself, extending cognitive processes to all living systems from single cells to complex multicellular organisms and their ecologies. This perspective fundamentally expands the taxonomic and organizational scope of cognitive science, questioning basic assumptions about the minimal requirements for cognitive activity and the relationship between life and mind. These positions are summarized in Table 1 below.

Table 1. Human-centered vs. Life-centered Approaches to Cognition and Intelligence.

Aspect	Human-Centered Approach	Life-Centered Approach
Cognitive process	Cognition is a mental process specific to humans.	Cognition is a somatic process of life (autopoietic coordination, anticipation, sense-making).
Environment coupling	Emphasis on internal mental processes. Extended/enactive views consider environment.	Always relational. Cognition as organism–environment coupling.
Cognition vs. Intelligence	Cognition = mental processes Intelligence = capacities of reasoning, problem-solving, learning in humans.	Cognition = ongoing life process; Intelligence = competency of that process under novelty, perturbation, and uncertainty.

1.3. Historical Development of Human-Centered Perspectives

The intellectual history of cognition and intelligence within human-centered traditions has three major developmental phases, each representing distinct theoretical commitments and methodological approaches that have shaped contemporary understanding.

Classical mentalism emerged from philosophical traditions that identified cognition with thinking and reasoning within mind–body dualistic frameworks. This approach treated mind and body as fundamentally distinct, the mind as non-physical and the body as physical, with cognition representing mental activity closely tied to conscious thought. Philosophical contributors including Descartes, Brentano, and early analytic thinkers established cognition as a defining characteristic of rational human minds, creating an explicitly anthropocentric foundation for subsequent theoretical developments.

In the mid-20th century, a paradigmatic shift in the "*cognitive revolution*" in psychology and artificial intelligence reframed cognition as symbol manipulation and abstract information processing. This transformation integrated Turing's computational concepts, problem-solving models, and systematic psychological frameworks to define mind as a symbolic information-processing system [2,3]. While maintaining human-centered assumptions, this computational metaphor replaced consciousness-based explanations with mechanistic models of mind as software operating on neural hardware.

Since the 1990s, embodied, embedded, enactive, and extended cognition (4E) frameworks have become prominent developments. These approaches argue that cognitive processes cannot be understood independently of their physical implementation and environmental context. Foundational contributions that established 4E cognition include [4–7]. This perspective emphasizes that cognitive processes emerge through situated bodily interactions and environmental contexts, fundamentally challenging earlier mentalist assumptions [8–10]. Within 4E frameworks, intelligence transcends abstract problem-solving capacity to encompass flexible coordination of body, brain, and environment for human goal achievement.

1.4. The Development of Life-Centered Perspectives

In contrast to human-centered theoretical developments, life-centered approaches have emerged that fundamentally reconceptualize the scope and nature of cognitive phenomena. Rather than restricting cognition to humans or organisms with nervous systems, this tradition identifies cognition with life processes themselves. Maturana & Varela's foundational insight that "*Living systems are cognitive systems and living as a process is a process of cognition*", established cognition as coextensive with biological organization [11].

Multiple theoretical contributions have developed this basic insight by emphasizing anticipation, sense-making, and problem-solving as fundamental features of living systems [12–15]. Within this framework, *cognition is the process of life itself*, while *intelligence is the competency of living systems to solve problems under conditions of novelty and uncertainty*.

While human-centric cognition has been characterized by "perception, memory, learning, decision-making, problem-solving, goal-directedness, attention, anticipation, communication, and maybe emotion" [16], evolutionary view of cognition describes cognitive capacities as gradually emerging across biological evolution, from simplest basal cognition (including basic cellular activities like sensing, memory, and goal-directed adaptation, that are found even in single-celled organisms) [14] to more complex organisms, rather than being restricted to organisms with nervous systems. As argued above, these two perspectives exist largely independently, with human-centered approaches dominating psychology, philosophy of mind and public understanding, whereas life-centered approaches are prevailing within biology, cybernetics, artificial life, and systems theory.

The consequences of this theoretical difference between two perspectives extend beyond academic discourse, shaping interpretations of life and mind and influencing conceptualizations of intelligence in an era increasingly defined by cognitive and intelligent technologies. Life-centered cognition receives precise articulation in contemporary biological frameworks: "*Cognition is comprised of sensory and other information processing mechanisms an organism has for becoming familiar with, valuing, and interacting productively with features of its environment in order to meet existential needs, the most basic of which are survival/persistence,* *growth/thriving, and reproduction*" [17]. This definition establishes cognition as fundamentally biological and providing criteria for identifying cognitive processes across the full spectrum of living systems.

2. The State of the Art on Human-Centered Perspective to Cognition and Intelligence

In psychology and philosophy of mind, cognition is defined as the set of mental processes—perception, memory, reasoning, language, problem-solving—through which humans acquire and use knowledge [2,18,19]. Intelligence is typically understood as a subset of these processes, specifically the ability to reason, solve problems, learn, and adapt effectively. This understanding has evolved through several research traditions, each contributing distinct insights into how cognition is structured, developed, and measured.

The developmental approach emerged through investigation of cognitive development, characterizing cognition as a developmental process of adaptation in humans operating through two complementary mechanisms: assimilation and accommodation. Within this framework, intelligence represents the capacity to adapt to the environment by effectively balancing these two processes [20]. This perspective established cognition as fundamentally developmental and adaptive, laying groundwork for subsequent theories that would emphasize the dynamic nature of cognitive processes.

Building upon developmental foundations, *the socio-cultural approach* introduced essential challenges to individualistic approaches. This tradition proposed that cognition develops through the internalization of social interaction, reshaping understanding of mental processes as inherently social phenomena. Intelligence, within this theoretical framework, constitutes the ability to use cultural tools, particularly language, to regulate thought and action [21]. This contribution established the essential role of social context in cognitive development and functioning, arguing that mental processes cannot be fully understood in isolation from cultural and interpersonal contexts.

The psychometric tradition was a methodological shift toward quantitative measurement of cognitive abilities. This perspective treated intelligence as quantitative measures derived from IQ testing, positioning cognition as the broader domain encompassing all mental processes [22,23]. These psychometric applications offered empirical methods for assessing individual differences in intellectual abilities. They have been criticized for cultural biases of IQ tests.

The information processing paradigm introduced computational description of human cognition as symbolic information processing occurring within formal problem spaces, with intelligence as efficient problem-solving capacity utilizing symbolic computation and explicitly using computational models [2]. The computational framework established formal methods for analyzing cognitive processes and problem-solving strategies, providing theoretical tools for characterizing mental operations.

The mainstream cognitive psychology has developed influential theoretical models of intelligence grounded in experimental studies of thinking, reasoning, memory, and problem-solving. An example is Sternberg's Triarchic Theory of Intelligence, which distinguishes analytical intelligence (problem-solving and reasoning), creative intelligence (the capacity to generate novel ideas and solutions), and practical intelligence (effective adaptation to real-world contexts) [23]. This framework sees intelligence as adaptive competence rather than as a single abstract capacity, and it explicitly connects laboratory-based cognitive research with everyday cognitive performance. Sternberg's work thus represents a central contribution within human-centered cognitive psychology, complementing both psychometric models and computational accounts of cognition.

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Contemporary cognitive science with *distributed cognition frameworks* challenges traditional computational approaches. Initial developments introduced microcognition, arguing that cognitive capacities emerge from *distributed*, *sub-symbolic processes* such as connectionist networks, rather than exclusively from symbolic rule-based reasoning [24]. This perspective evolved into the Extended Mind Hypothesis, proposing that cognition extends beyond individual minds into the body and environment through tools and artifacts [5]. Recent theoretical developments incorporate predictive processing, describing cognition as the brain's systematic attempt to minimize prediction errors through environmental interaction [25]. Within this framework, cognition is distributed and embodied, while intelligence represents the capacity to flexibly integrate micro-level processes, bodily resources, and environmental supports for problem-solving.

This theoretical development has culminated in perspectives that extend cognition beyond traditional boundaries of the human mind and brain, incorporating environmental elements that perform cognitive functions such as memory extension and computation. Contemporary approaches thus dissolve the conventional boundary between human cognition and the surrounding environment, proposing that cognitive functions are distributed throughout broader ecological systems. This represents a fundamental shift from individualistic models toward understanding cognition as an emergent property of individual-environment interaction systems, which establishes the foundation for even more radical reconceptualizations of cognitive processes.

3. The State of the Art on Life-Centered Perspectives to Cognition and Intelligence

The life-centered perspective redefines cognition and intelligence by grounding these phenomena in the basic processes of living systems themselves. This theoretical shift moves beyond brain-centric models to examine cognitive processes as intrinsic properties of life, establishing cognition not as an emergent property of complex neural networks but as a fundamental characteristic of processes in biological organization that appears in degrees.

This shift is motivated by the observation that living systems exhibit adaptive behaviors across all scales of biological organization, down to single cells. The fundamental insight by Maturana and Varela that all living systems are cognitive, and that living is a process of cognition [11], established cognition as synonymous with autopoiesis, the organism's self-producing and self-maintaining process coupled structurally with its environment. Intelligence, within this framework, represents higher-order capacities such as language or symbolic reasoning that build upon the fundamental cognitive substrate inherent in all living systems.

The ecological dimension of this approach emphasizes cognition as pattern recognition and utilization within broader environmental contexts. Rather than viewing minds as isolated symbolic information processors, this perspective sees cognition as the basic capacity of a system to recognize, analyze, and organize differences in order to create knowledge and communicate with its environment. Arguments by Bateson [12] against the separation of mind and body, suggested that the same fundamental patterns of interaction and relationship govern all biological systems, including humans. Cognition, in this view, is not an isolated internal process but an emergent property of systems that are interconnected with their environment, in "the pattern that connects" [12]. According to Bateson, the mind is a machine that computes and contrasts these variations, therefore it applies not only to people but also to any biological system that has the ability of perception. Through a cybernetic understanding of systems and information, this constructivist process entails the detection of differences that make a difference and the creative adaptation of these patterns to novel circumstances [26]. Intelligence emerges through flexible, creative responses that control these relational patterns across varying environmental conditions.

3.1. Anticipatory and Self-Reflective Nature of Life

Essential to life-centered perspective is the insight that living systems are inherently anticipatory. The capacity to construct models of both self and environment enables organisms to predict future states and guide adaptive action accordingly [13]. This anticipatory modeling represents a form of cognition that extends beyond reactive stimulus-response mechanisms, involving predictive elements that enhance survival and adaptation across diverse biological contexts.

The reflexive nature of biological cognition introduces additional complexity through self-referential processes. Living systems not only process environmental information but also monitor and modify their own cognitive processes, creating recursive feedback loops that enable adaptive reorganization [27]. This second-order cybernetic capacity allows organisms to adapt not merely to environmental changes but to their own changing cognitive states and capabilities.

Semiotic approaches provide another important perspective on biological cognition. The processing of iconic, indexical, and symbolic signs occurs across multiple levels of biological organization, from basic cellular signaling to complex symbolic reasoning [28,29]. While symbolic reference reaches its highest expression in human cognition, the underlying semiotic processes are present throughout living systems, creating a hierarchical understanding of cognitive complexity from simple organisms to social systems.

Contemporary mathematical and computational frameworks have formalized these insights through the Free Energy Principle and Active Inference [30]. This approach characterizes cognition as the ongoing attempt of living systems to minimize "surprise" or prediction error through continuous environmental modeling and active engagement. Intelligence manifests as the competency with which systems maintain homeostasis and viability under uncertain conditions, providing quantitative measures for cognitive effectiveness across biological scales.

The scope of life-centric approach extends cognition to organisms traditionally considered non-cognitive. Recent research shows that bacterial colonies, slime molds, and other basal organisms have sophisticated problem-solving capacities without nervous systems [14,31]. These findings challenge neurocentric assumptions and establish cognition as a general property of living systems, with intelligence reflected in behavioral flexibility and adaptive resilience.

Scale-invariance represents a significant aspect of life-centered cognition. The capacity to navigate abstract state-spaces of possible configurations is found across cellular, tissue, organ, and organism levels [15,32]. Individual cells exhibit goal-directed behavior, tissues coordinate collective actions, and organisms pursue complex objectives—all demonstrating cognitive processes that transcend traditional boundaries between different levels of biological organization.

3.2. Empirical Evidence

Empirical evidence supports these theoretical propositions of life-centric cognition and intelligence. It shows that slime molds (*Physarum polycephalum*) solve complex spatial problems and anticipate periodic environmental changes despite lacking neural structures [33]. Bacterial communities engage in collective decision-making through quorum sensing, coordinating metabolic transitions based on population dynamics [34,35]. Planarian regeneration demonstrates how cellular systems maintain morphological memories and reconstruct complex body plans following injury [36]. These experimental results show cognition as a distributed property of living matter rather than a specialized function of nervous systems or exclusively human brains.

This establishes a fundamental relationship: cognition represents the basic process of life itself, the maintenance and adaptation of living systems, while *intelligence* measures the competency with which these processes of life *achieve goals under varying conditions*. Rather than viewing cognition and intelligence as unique emergent properties of complex brains, the life-centered perspective reveals them as fundamental characteristics of evolving biological organization, present in degrees in all life.

4. New Computationalism: Information Processing and Natural Computation

The traditional association of computation with disembodied symbol manipulation has created an artificial opposition between computational and embodied approaches to cognition, leading many researchers to reject computational frameworks as a priory incompatible with enactive alternatives. However, this rejection stems from a restrictive understanding of computation unaware of the broader spectrum of computational processes operating in biological systems. Contemporary developments in computational theory have fundamentally expanded the concept of computation beyond classical abstract symbolic Turing-machine models to encompass sub-symbolic, interactive, natural, and physical forms of information processing [9]. On this broader view, computation can be understood as embodied and dynamically realized information processing in the organization and activity of living systems. This expanded computational landscape includes computation spanning a diverse spectrum—from algorithmic and symbolic processes to interactive, morphological, and other embodied natural forms [37]. Biological systems exemplify these latter computational processes that surpass predefined algorithmic execution, instead computing through physical reorganization in interaction with internal and external signals known as interactive computing [38].

4.1. Dynamical Approaches to Cognition

In contrast to classical cognitive science, which treats cognition as discrete symbol manipulation, the dynamical perspective understands cognition as trajectories through continuous state spaces shaped by attractors, stability, and non-linear interactions. In this framework, computation is identified with the system's intrinsic dynamics rather than with algorithmic symbol processing. Cognitive behavior is explained through time-dependent coordination among neural processes, often focusing on the brain as the primary cognitive substrate. As van Gelder [39] argues, cognition is not merely something that unfolds over time but is fundamentally constituted by temporal dynamics themselves.

Dynamical approaches played a crucial role in challenging representational and computational orthodoxies in classical cognitivism by demonstrating how adaptive behavior can emerge from continuous system–environment interaction. However, they typically focus on neural dynamics and do not account for symbolic computation or cognition beyond brain-centered processes. In a more general approach to cognition in nature, living organisms are viewed as self-modifying computational agents [40], in which structure and process co-evolve. Their organization is not fixed; it is continually reconstructed through development, metabolism, learning-like adaptation, and multi-level regulation. This dynamic self-modification provides a bridge between computational descriptions and embodied, enactive accounts of cognition.

The recognition of diversity of possible types of computation shows how biological systems implement different processing strategies across organizational scales. Symbolic computation operates through rule-based manipulation of discrete symbols, as in digital

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computers and formal logic systems following Turing machine models. Sub-symbolic computation encompasses pattern recognition processes without explicit symbol use, manifested in neural networks and reflex behaviors in living systems through connectionist architectures. Morphological computation embeds information processing within physical form and dynamics, found in plant growth patterns and slime mold adaptive behaviors. Bioelectric and self-modifying computation involves recursive reconfiguration of structure and dynamics based on internal feedback, evident in regenerative repair processes and tissue morphogenesis. Info-computation represents integrated processing of form, information, and value regulation emerging in different forms across all levels of biological organization from cellular systems to complex cognition [41,42].

Several contemporary theoretical frameworks have formalized these new insights. Predictive processing and Free Energy Principle with Active Inference represent influential developments that model cognition as probabilistic inference and self-organizing regulation [30]. Cognitive systems engage in continual minimization of surprise (prediction error) through updating generative models of environmental conditions. Computation in this approach is information processing of probabilistic patterns distributed across neural and physical systems, rather than exclusively logical symbol manipulation on the symbolic/human-language level. On this view, cognition can be interpreted as natural computation implemented in the dynamics of living systems that maintain themselves within viable bounds. Intelligence then is the competence of such systems to solve problems through adaptive inference and regulation under uncertainty. This reframes intelligence from an abstract, disembodied problem-solving capacity to an embodied competence expressed in perception–action loops and multi-level control. Table 2 summarizes the above discussed computational models.

Table 2. Types of Computation in Biological Systems. Data from [10,40–45].

Computation	Definition	Biological Example	Reference Model
Symbolic	Rule-based manipulation of discrete symbols	Digital computers, neural networks logic	Turing machine models
Subsymbolic	Pattern recognition without explicit symbol use	Neural network and cells subsymbolic, reflex arcs	Connectionist models
Morphological	Computation embedded in physical form and dynamics	Plant growth, slime mold adaptation	Pfeifer & Bongard [10] Hauser et al.
Self-modifying systems	Recursive reconfiguration based on internal feedback	Basal cognition, morphogenesis	Kampis [40]
Info-computation	Integrated processing of information (morphological computation); value-regulation	All levels of life—cells to ecologies	Dodig-Crnkovic [41–44], Ehresmann [46]

Morphological, Bioelectric, Self-modifying and Info-computational models are all sub-symbolic. Table from [42].

4.2. Info-Computational (Morphological) Approaches to Cognition

Info-computational approaches to cognition adopt a broader conception of computation as the physical processing of information through the organization and dynamics of matter (morphological computing). Rather than identifying computation exclusively with neural dynamics or symbolic algorithms, these frameworks treat computation as an intrinsic feature of physical systems, operating across multiple scales of biological organization.

Within this perspective, both sub-symbolic and symbolic computational regimes are accommodated. Sub-symbolic computation is realized through continuous, distributed, morphogenetic processes, while symbolic computation emerges at higher organizational levels through stabilized relational structures and compositional constraints. Formal mathematical models developed by Ehresmann (2014) [46] explicitly articulate how symbolic computation arises from, and remains constrained by, sub-symbolic dynamics within a unified multilevel framework of info-computation.

Morphological computation emphasizes how physical structure itself participates in information processing, allowing organisms to compute through their form, material properties, and ongoing self-organization. This makes info-computational approaches applicable to both discrete and continuous systems and to a wide range of biological entities, from cells and tissues to whole organisms and cognitive agents. In contrast to dynamical cognition, which focuses on temporal trajectories, info-computation foregrounds organizational structure, multiscale integration, and life-wide applicability.

A synthesis of embodied info-computation in nature (ICON) is given by Dodig-Crnkovic [41–43]. This approach unifies symbolic and sub-symbolic processes within a broader view of computation in which form (information, morphology), and function (its dynamics) co-evolve. Cognition includes the regulation of living processes through dynamic interactions relating matter, energy, and info-computation. Living systems, on this account, can be described as morphologically computing agents that reconstruct their organization in response to environmental inputs and internal regulatory demands, effectively computing their subsequent states through embodied processes. This perspective supports continuous spectrum of cognition that encompass the full range of living systems extending cognitive functions beyond humans and animals with nervous systems through functional equivalence on different levels of organization.

This reconceptualization dissolves the alleged contradiction between computational and embodied approaches by showing computation itself as necessarily embodied in natural systems. Rather than opposing computation to embodiment, contemporary information processing frameworks [8] demonstrate that the most sophisticated forms of biological computation emerge precisely through embodied processes that integrate information processing with physical organization.

Intelligence and cognition thus represent different aspects of the same fundamental phenomenon: the capacity of living systems to process information through their own organizational dynamics while maintaining adaptive relationships with their environments.

5. A Unifying Framework for Cognition and Intelligence

The diversity of approaches surveyed in the preceding sections reveals a persistent conceptual ambiguity concerning the relationship between cognition and intelligence. This ambiguity arises in part from the tendency to treat intelligence either as a general adaptive capacity or as an independent property detached from the processes of life. In order to resolve these tensions, a clear conceptual distinction is required, together with an explicit account of how cognition and intelligence are related.

The framework proposed here begins by distinguishing between three levels of organization: physical adaptation, cognition, and intelligence. Many physical systems exhibit adaptive reorganization under changing environmental conditions. Fluids, for example, continuously adjust their configuration in response to external constraints, and dissipative systems maintain dynamic stability through ongoing exchange with their surroundings. However, such processes do not constitute cognition. They lack any internally organized regulation of interaction and do not define or resolve problems. Their behavior is entirely determined by external conditions and intrinsic physical dynamics.

Cognition arises with living systems. It is the ongoing process through which a system senses, regulates, and coordinates its interaction with the environment in order to maintain its organization. Cognition is thus inherently relational and embodied, grounded in continuous interaction between system and environment. It does not presuppose consciousness or symbolic reasoning, but is present in degrees across all forms of life, from basic cellular regulation to complex organismic and social processes. In this sense, cognition is coextensive with life understood as an autopoietic, sense-making, adaptive organization.

Intelligence is a further specification within cognition. It cannot be reduced to general adaptation or to the mere capacity for reorganization. Instead, intelligence refers to the capacity of a cognitive system to solve problems in a goal-directed manner under conditions of novelty, perturbation, and uncertainty. This introduces two essential features that distinguish intelligence from both physical adaptation and basic cognition: the existence of system-relative goals, and the ability to navigate a space of possible actions in relation to those goals.

Goal-directedness is understood here in a minimal, non-anthropomorphic sense. It does not require conscious intention or explicit representation, but refers to the organization of activity toward maintaining or achieving specific states. In biological systems, such goals are intrinsic to the organization of the system itself, including persistence, viability, growth, and reproduction. In artificial systems, goals may be externally specified or learned through interaction. What is essential is not the origin of the goal, but the system's capacity to organize its activity in relation to it.

On this basis, intelligence can be characterized as the competence with which a cognitive system organizes and reorganizes its activity to resolve problems arising in its interaction with the environment. Problem solving, in this context, does not necessarily imply explicit symbolic reasoning, but includes any capacity to select, coordinate, and modify actions so as to achieve system-relevant goals under changing conditions. Intelligence thus appears in degrees, depending on the flexibility, robustness, and effectiveness with which such problem-solving processes are carried out.

This distinction establishes a hierarchical relationship between the three levels. Physical systems may exhibit adaptive dynamics without cognition. Living systems exhibit cognition as the regulation of interaction. Intelligent systems—natural or artificial—exhibit goal-directed problem solving grounded in cognition. Intelligence therefore presupposes cognition, and cognition presupposes a form of organized, self-maintaining interaction with the environment.

Within this framework, existing approaches can be understood as emphasizing different aspects of the same underlying process. Life-centered theories, including autopoiesis, correctly identify cognition with the processes of living organization, but often leave the distinction between basic regulation and higher-order problem solving implicit. Enactive and embodied approaches emphasize the relational and interactive character of cognition, highlighting sense-making and environmental coupling. Computational and information-processing approaches, when extended beyond classical symbolic models, provide formal descriptions of the mechanisms through which such regulation and problem solving can occur. Predictive processing and related frameworks offer one possible formalization of cognitive regulation in terms of the minimization of prediction error, but do not exhaust the range of possible implementations.

The present framework integrates these perspectives by treating cognition as embodied information processing in interaction, and intelligence as the problem-solving competence of that process. In this way, it avoids both the restriction of cognition to human mental processes and the dilution of intelligence into general adaptive dynamics.

This distinction has direct implications for artificial intelligence. Classical AI systems have typically treated intelligence as disembodied problem-solving performance, largely independent of ongoing interaction with a physical environment. Within the present framework, such systems exhibit limited forms of intelligence but do not fully instantiate cognition, as they lack continuous regulation of organism–environment interaction. As

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artificial systems become increasingly embodied, autonomous, and adaptive, incorporating perception, action, learning, and environmental coupling, they approach forms of cognition in this broader sense. Their intelligence can then be evaluated not only in terms of task performance, but in terms of their capacity for goal-directed problem solving grounded in ongoing interaction.

The proposed framework thus provides a coherent conceptual basis for understanding cognition and intelligence across both natural and artificial systems. It clarifies their relationship, establishes necessary distinctions, and offers criteria for identifying and comparing different forms of cognitive and intelligent behavior across levels of organization. Table 3 summarizes the cognitive status and forms of intelligence across natural and artificial systems within the proposed framework.

Table 3. Cognitive status and intelligence across natural and artificial systems.

System Type	Cognition	Intelligence	Source of Goals/Normativity
Unicellular organisms	Basal autopoietic sensing and regulation	Adaptive problem-solving in viability space	Intrinsic viability in the Umwelt
Multicellular organisms	Coordinated embodied cognition	Learning, anticipation, and flexible action	Distributed Organismic Umwelt viability
Humans	Biological cognition extended by language and culture	Symbolic, social, technical, and reflective problem-solving	Umwelt + Cultural Welt viability
Current AI	Based on human-produced compressed information with human-defined goals	Learning from human data, Solving synthetic/ derivative problems	Humans
Embodied AI	Cognition-like architecture if embodied and self-regulating, but still not autopoietic	Adaptive problem-solving	Human
Hybrid human-AI	Cognition anchored in human agents	Distributed problem-solving	Human (including institutions)

6. Comparative Analysis of Approaches to Cognition and Intelligence

The difference between human-centered and life-centered perspectives can be clarified through comparison of their underlying assumptions and explanatory aims. In the human-centered view, cognition is restricted to the workings of the human mind, and intelligence is treated as a measure of specific human mental abilities.

In the life-centered view, cognition is understood as coextensive with life itself and an organism's way of maintaining itself, interacting with its environment, making sense of the world and reaching its goals. Intelligence then is the *competency* of this ongoing process to cope flexibly with change and uncertainty, *its ability to solve problems, posed by cognition*.

The implications of perspective are significant: in the first view, cognition is an exclusively human or at most brain-based phenomenon, while in the second it is a property of all living systems, from single cells to humans, manifesting in degrees. There are also approaches which bridge the two, such as proposed by Clark [25] organism-centered discussions of living cognition [16]. Table 4 presents the comparison between different approaches to cognition and intelligence.

Table 4. Cognition vs. Intelligence in Different Approaches.

Researcher	Cognition	Intelligence	Center
Piaget [20]	Developmental process of adaptation (assimilation & accommodation).	Capacity to adapt to environment by balancing assimilation/accommodation.	Human
Vygotsky [21]	Socio-cultural, shaped by language/tools.	Ability to use cultural tools for regulation.	Human
Bateson [12]	Mind as "a pattern that connects"; cognition as ecological.	Intelligence = adaptive use of patterns; creativity in systems.	Life
von Foerster [27]	Constructive, observer-dependent; second-order cybernetics.	Recursive adaptation in observer–system interactions.	Life
Neisser [3]	Human mental processes	Reasoning, problem-solving, learning).	Human
Rosen [13]	Living systems model themselves & environment.	Ability of models to anticipate.	Life
Maturana & Varela [11]	Living systems are cognitive systems.	Higher-order capacities (e.g., coordination, language,) built on basic cognition.	Life
Gardner [47]	Multiple modalities of processing.	Multiple intelligences: linguistic, musical, etc.	Human
Carroll [22]	Factor-analytic structure.	Measured across domains (psychometrics).	Human
Newell & Simon [2]	Information-processing in symbolic spaces.	Efficient search/problem-solving.	Human
Deacon [28,29]	Semiotic process (iconic, indexical, symbolic).	Symbolic reference on top of biological cognition.	Life
Clark [24,25]	Distributed (microcognition), extended into environment, predictive processing.	Competency in flexibly integrating internal & external resources.	Bridge
Friston [30]	Active inference minimizing surprise	Competency in minimizing uncertainty.	Life
Lyon [14]	Exists in basal organisms; cognition without brains.	Viable range of behaviors under survival.	Life
Levin [15,32]	Navigating state-spaces, scale-invariant across life.	Competency in reaching goals by different means.	Life

The visualization of the above table is given in Figure 1 which presents a qualitative positioning of approaches to cognition, (Symbolic → Embodied) vs. (Human-centered → Life-centered). Circles are non-computational approaches, squares are computational. With each symbol there is a name of the representative philosopher/scientist.

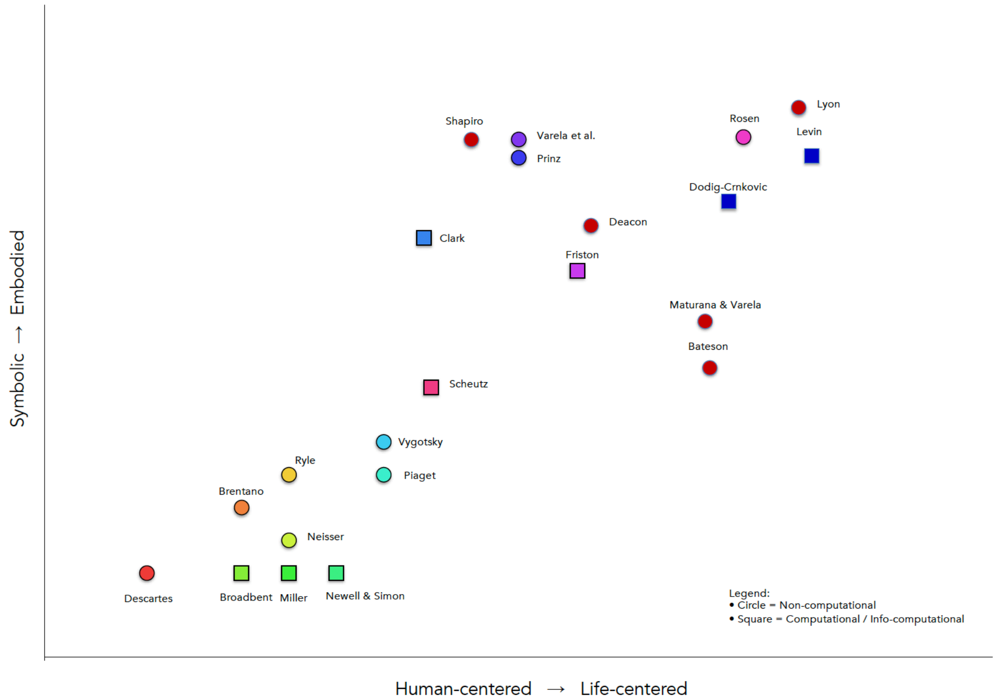

Figure 1. Landscape of Approaches to Cognition.

7. Limitations and Future Research

The proposed framework is conceptual rather than an operational theory. It proposes information, computation, and cognition/observer-agency as minimal relational elements for comparing systems across levels of organization. Information concerns structured differences; computation concerns their transformation; cognition concerns the observer-agent for which differences matter and by which transformations become functional. The framework is therefore not a single metric of intelligence, but a grammar for asking what information, computation, and cognition mean at each organizational level. Operationalization must remain level- and domain-specific.

The cognitive status of artificial systems remains open. Current systems can be intelligent in an engineered sense without being cognitive in the biological sense. Future artificial, synthetic, or hybrid systems may require new categories if they develop forms of autonomous self-maintenance, persistent goals, and embodied regulation that are not reducible to externally supplied task performance. At present, such possibilities remain open research questions.

8. Conclusions

The exploration of cognition and intelligence across diverse theoretical traditions reveals fundamental conceptual tensions. Despite their centrality to multiple disciplines, these concepts remain insufficiently understood, largely due to definitional frameworks that fail to capture the full scope of contemporary scientific understanding.

Two broad orientations organize the field. The human-centered approaches conceptualize cognition as a set of distinctively human *mental processes*, with intelligence treated as a set of *cognitive capacities* including reasoning, problem-solving, learning, and adaptation [3,23]. This perspective tends to restrict cognition to organisms with advanced neural architectures and often emphasizes abstract symbolic operations, even when embodied and extended accounts are included [2,48].

In contrast, the life-centered perspectives identify *cognition with the process of life* itself, recognizing *intelligence as the competency of living systems to solve problems* under conditions of novelty and uncertainty [11,14]. This perspective expands the scope of cognitive science by demonstrating that cognitive processes operate across all levels of biological organization, from cellular systems to complex multicellular organisms and their networks [15].

This theoretical split manifests through parallel development within distinct disciplinary contexts. Human-centered perspectives prevail in philosophy of mind, mainstream psychology, neuroscience, and public discourse, while life-centered approaches are dominant within neuroscience, biology, systems theory, information studies and cybernetics [12,13]. Their consequences are shaping scientific practice and technological development.

Historically, artificial intelligence has treated intelligence as largely separable from cognition, reflecting the software-based and disembodied nature of early AI systems. In this context, intelligence was defined in terms of problem-solving performance, optimization, or task competence, without requiring perceptual grounding, embodiment, or ongoing interaction with the physical world. As artificial intelligence is increasingly implemented in embodied, autonomous, and adaptive systems such as robots, cyber-physical systems, and intelligent agents operating in real-world environments, this separation is disappearing. Perception, sensorimotor coordination, learning, anticipation, and context-sensitive adaptation become central design concerns, bringing artificial systems into closer conceptual alignment with cognitive processes as understood in biological organisms. This shift is reflected in emerging fields such as cognitive computing and cognitive robotics, which explicitly integrate cognitive principles into the development of intelligent systems.

The theoretical perspectives on cognition outlined in this paper imply different principles for the design of artificial systems. In classical symbolic approaches, where cognition is identified with internal information processing, artificial intelligence is implemented as problem-solving over formal representations, largely independent of ongoing interaction with the environment. In contrast, embodied and enactive approaches emphasize that cognition arises through continuous sensorimotor coupling, leading to the design of systems that integrate perception, action, and real-time feedback in dynamic environments. Life-centered and info-computational perspectives extend this further by interpreting cognition as the regulation of interaction characteristic of living systems. From this standpoint, the design of intelligent systems requires not only computational performance but also the integration of sensing, internal state regulation, and adaptive coordination across multiple levels of organization. In engineering-oriented research, approaches such as *Mindful Machines* [49] similarly aim to construct adaptive, goal-directed artificial systems by integrating knowledge representation, control, and meta-level regulation, illustrating one possible implementation of these principles.

Within the framework proposed here, these approaches can be understood as addressing different aspects of cognition and intelligence. Systems that optimize task performance without sustained interaction may exhibit forms of intelligence in a limited sense, but lack cognition as ongoing regulation of interaction. Conversely, systems that incorporate continuous interaction, learning, and adaptation approach cognition in a broader sense and enable more robust forms of intelligence. This distinction provides a conceptual basis for evaluating artificial systems not only in terms of performance, but in terms of how their organization supports goal-directed problem solving under conditions of uncertainty.

In medicine and neuroscience, life-centered perspectives transform practice by recognizing that cells, tissues, and organ systems exhibit cognitive properties including memory, learning, and decision-making [15]. This insight reshapes approaches to regenerative medicine and cancer research by recognizing cognitive processes at cellular level [32]. Synthetic biology as well benefits from using natural cognitive capacities for autonomous, adaptive biotechnological solutions [50].

Developments in morphological computation, predictive processing, and info-computationalism reveal that computational and embodied approaches can be integrated when computation is understood as necessarily embodied in natural systems [30,43,51]. These frameworks suggest that complex intelligence emerges in nature by integrating information processing with physical organization through evolutionary and developmental processing in living systems.

Rather than viewing anthropocentric and biocentric perspectives as mutually exclusive, future research may benefit from recognizing their complementary insights. Human-centered approaches are good at analyzing complex symbolic reasoning and conscious experience in humans, while life-centered approaches reveal fundamental cognitive processes underlying all biological organization, including the role of human body for human cognition. The choice between these theoretical frameworks reflects deeper commitments about mind and life that shape both scientific inquiry and technological development.

The proposed unifying approach defines cognition as the ongoing process through which living systems interact with and regulate their relationship with the environment, while intelligence is the competence of those processes in solving problems under changing conditions, appearing in degrees across the spectrum of living systems. As we enter an era defined by intelligent and cognitive technologies, these theoretical foundations can help us determine how we model and design those systems.

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