An Ontosemiotic Framework for Biosemiotic Analysis of Living Systems[1]

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Abstract

Biosemiotics provides a robust account of life as a sign-based and interpretive phenomenon, grounded in the Peircean tradition and in Jakob von Uexküll's foundational concept of the *Umwelt*. However, a persistent theoretical challenge in the field concerns the systematic articulation between biological processes and semiotic processes. This article argues that this challenge can be clarified by incorporating analytical tools from the Ontosemiotic Approach (OSA) to activity, meaning, and cognition. The OSA offers a coherent framework for relating ecological contexts, problematic situations, practices, processes, objects, and relations, with particular emphasis on the situated activity of autonomous agents and on the conditions under which signs are produced and interpreted. The concept of *semiotic function* extends existing biosemiotic analyses of biological codes by specifying both the types of objects placed in correspondence and the contextual conditions under which such correspondences acquire meaning. We propose an ontosemiotic model structured into three analytical levels— (1) context, problem and practices, (2) primary processes and objects, and (3) secondary processes and objects—and demonstrate its applicability to semiosis in living systems. As an illustrative case, we analyze the hunting activity of the red fox (*Vulpes vulpes*) as a prototypical instance of individual-level semiosis within an ecosystem. The analysis shows that biosemiotic accounts are substantially enriched when the ontological structure of the domain in which semiosis occurs is made explicit, suggesting that the OSA constitutes a complementary and generalizable framework for understanding semiosis in living systems.

Keywords: Biosemiotics; autonomous agency; ecosystem; ontosemiotic approach; semiotic function; theoretical articulation.

1. Introduction

Over the past decades, biosemiotics has consolidated itself as an interdisciplinary field devoted to understanding life in terms of signs, codes, and interpretive processes (Barbieri, 2009; Favareau, 2010; Hoffmeyer, 2008). Rooted in Peircean semiotics and in Jakob von Uexküll's theoretical biology, this approach maintains that living processes cannot be exhaustively explained by physico-chemical mechanisms alone, but necessarily involve dynamics of signification and communication. From this perspective, semiosis— the production and interpretation of signs—is not an emergent feature restricted to human cognition, but a fundamental characteristic of life as such. Signs and sign relations, accordingly, permeate all levels of biological organization.

In this sense, biosemiotics approaches life as a symbolic phenomenon: a "web of signs and messages" that extends far beyond the human domain. Nevertheless, one of the core

theoretical challenges of biosemiotics remains the systematic articulation between biological processes and semiotic processes. While the field has developed powerful conceptual tools—such as *Umwelt*, biological codes, semiotic niches, and semiotic agency—there is still a need for analytical frameworks capable of describing, in an integrated way, the ecological contexts in which biological activities unfold, the problematic situations that motivate them, and the practices, processes, objects, and relations involved in their resolution.

The Ontosemiotic Approach (OSA) to mathematical and scientific activity (Godino, 2004; Godino et al., 2007) offers a set of conceptual and methodological tools that can enrich biosemiotic analysis. In particular, the notions of *ontosemiotic configuration* and of the three levels of ontosemiotic analysis enable a systematic examination of activity in terms of problems, practices, processes, and objects, all situated within specific contexts. Originally developed to clarify the nature of mathematical knowledge and cognition, the OSA provides a general framework for analyzing meaning as it emerges from the activity of autonomous agents.

By incorporating the OSA into biosemiotics, it becomes possible to move beyond a focus on the internal structure of signs or codes and toward an analysis of the *function* of signs within situated activities. This shift foregrounds the role of intentional activity—understood here in a biological, non-conscious sense—in the production and interpretation of signs. Living systems are thereby characterized as autonomous agents engaged in problem-solving activities oriented toward homeostasis, survival, and reproduction. Although propositional and discursive practices are specific to higher cognitive agents, communicative processes—understood broadly as the production, transmission, and interpretation of signals—are pervasive across living systems.

In this article, we argue that the OSA can be meaningfully applied to the study of living physical systems insofar as these systems exhibit autonomous agency. Living organisms "do things" in order to respond to problematic situations that affect their viability and persistence. Living, in this sense, is an activity carried out by certain physical systems that display a form of biological *know-how*, implementing operative and communicative practices while inhabiting ecological communities structured by the exchange and interpretation of information.

The structure of the article is as follows. Section 2 reviews the semiotic tools most commonly employed in biosemiotic research. Section 3 introduces the main assumptions of the Ontosemiotic Approach and presents the notion of ontosemiotic configuration, together with the three analytical levels used to study the activity of an autonomous agent. In Section 4, these tools are applied to a case study of the hunting activity of the red fox (*Vulpes vulpes*), proposed as a prototypical example of individual-level biological semiosis. Section 5 compares the contributions of the OSA with other formalization efforts in biosemiotics. The article concludes by summarizing the main theoretical implications and outlining directions for future research.

2. Semiotic Tools Used in Biosemiotic Studies

The conceptual foundations of biosemiotics have been developed across a plurality of approaches and research traditions, as reflected in the wide-ranging contributions collected in Favareau's (2010) anthology. Biosemiotics, understood as an integrative research program linking biology and semiotics, holds that processes of signification are constitutive of life at all organizational levels. Rather than treating signs as secondary or

derivative phenomena, it conceptualizes semiosis as an intrinsic dimension of biological organization, from molecular interactions to ecological and behavioral dynamics. To articulate this perspective, the field has developed a set of conceptual tools that allow biological phenomena to be interpreted as processes of sign production, transmission, and interpretation. This section provides a concise synthesis of the semiotic constructs most commonly employed in biosemiotic research and situates them with respect to the analytical contribution proposed in this article.

2.1. Peirce's Triadic Model and Unlimited Semiosis

Charles Sanders Peirce's theory of the sign constitutes one of the foundational pillars of biosemiotics. Peirce defines the sign as a triadic relation among *representamen*, *object*, and *interpretant*, emphasizing that semiosis is not reducible to a dyadic stimulus–response mechanism (Peirce, 1931–1958, CP 5.438–463). Meaning emerges not from direct correspondence but from an interpretive process in which a sign gives rise to another sign, potentially without limit.

This conception of unlimited semiosis has proven particularly fruitful for modeling biological phenomena such as cellular signaling, genetic regulation, and behavioral coordination. Rather than being explained solely in causal or mechanistic terms, these processes can be understood as chains of interpretation embedded within functional cycles. As Queiroz et al. (2010) argue, this perspective allows biological organization to be conceptualized as a network of habits and regularities maintained through semiotic processes, thereby integrating normativity and interpretation into the heart of biological explanation.

2.2. Biological Codes and Organic Meaning: Barbieri's Perspective

Complementing the Peircean framework, Barbieri's theory of biological codes introduces a distinct but compatible approach to semiosis in living systems. Barbieri (2008, 2024) defines a biological code as a set of rules that establish correspondences between two independent domains through the mediation of molecular adaptors. The genetic code, which links nucleotide triplets to amino acids, is the paradigmatic example: its structure cannot be derived from physico-chemical necessity alone but reflects historically stabilized normative constraints.

A key contribution of this framework is the distinction between *coded semiosis*, which operates universally in living systems, and *interpretive semiosis*, which characterizes organisms endowed with nervous systems and higher cognitive capacities. This distinction broadens the scope of biosemiotics by allowing semiosis to be attributed to all forms of life without conflating molecular regulation with conscious interpretation. At the same time, it raises the question of how codes acquire functional meaning within concrete biological activities—a question directly addressed by the ontosemiotic framework proposed in this article.

2.3. Structuralism and Information-Theoretical Approaches

Biosemiotics has also incorporated insights from structuralist semiotics and information theory. From a structuralist perspective, inspired by Saussure, signs are defined relationally rather than substantively: meaning arises from differential positions within a system. This idea has been adapted to biological contexts, where molecular patterns, metabolic pathways, and ecological interactions are understood as structured networks in which functional significance depends on relational position rather than intrinsic properties.

Information theory, from Shannon's foundational formulation (1948) to more recent biosemiotic reinterpretations (e.g., Deacon, 2021), has contributed analytical tools for examining signal transmission, constraint, and organization. In biosemiotics, information is not treated as a purely quantitative measure but as "a difference that makes a difference" for an organism's activity. This reconceptualization supports an understanding of biological organization as emerging from constrained flows of information that are interpreted relative to the organism's needs and capacities.

2.4. Meaning as Biological Value and Semiotic Fitness

One of the central contributions of biosemiotics is the articulation of meaning in terms of biological value. Following Jonas's (1966) philosophical biology, living systems are characterized by self-maintenance and active resistance to entropy. This existential condition transforms environmental signals into matters of concern for the organism, thereby grounding semiosis in vital needs.

From this perspective, the meaning of a sign is defined by its adaptive relevance—what Hoffmeyer (2011) and Kull et al. (2009) describe as *semiotic fitness*. Signs guide action insofar as they contribute to the organism's capacity to maintain itself, reproduce, and persist within its ecological niche. Classical examples include bacterial chemotaxis, where chemical gradients function as signs that orient movement toward nutrients. Meaning, in this sense, is neither subjective nor arbitrary but rooted in the organism–environment relation.

2.5. The Umwelt and the Situated Nature of Meaning

Jakob von Uexküll's concept of the *Umwelt* provides a cornerstone for biosemiotic accounts of meaning as a situated phenomenon. Each organism inhabits a species-specific world of significance structured by its perceptual capacities, motor possibilities, and biological needs (Uexküll, 1940/1982). Objects do not possess meaning in themselves; rather, they acquire significance within the functional relations that constitute the organism's Umwelt.

This framework underscores the relational and perspectival nature of semiosis. Meaning emerges at the interface between organism and environment and is inseparable from the organism's mode of life. The Umwelt concept thus provides a crucial link between semiotic processes and ecological context, reinforcing the idea that semiosis is always embedded in concrete practices of perception and action.

2.6. Additional Core Concepts in Biosemiotics

Several additional constructs have been developed to refine the biosemiotic understanding of living systems:

- *Semiotic scaffolding* (Hoffmeyer, 2008): networks of semiotic controls that guide processes such as development, physiological regulation, and behavior.
- *Code duality* (Hoffmeyer & Emmeche, 1991): the interaction between digital codes (e.g., DNA) and analog codes (e.g., ecological dynamics).
- *Semiotic freedom* (Hoffmeyer, 1992; Wiley, 1994): the degree of interpretive flexibility available to an organism.
- *Semiotic niche* (Hoffmeyer, 1996): the subset of environmental signs relevant to an organism's survival.
- *Semiosphere* (Lotman, 1984; Hoffmeyer, 1996): the global space of interconnected semiotic processes permeating the biosphere.

- *Semiotic agency* (Hoffmeyer, 2013; Sharov, 2010, 2018): the conception of organisms as autonomous agents capable of acting through interpretation.

Taken together, these concepts provide a rich theoretical toolkit for describing life as a semiotic phenomenon. However, they are often deployed in a complementary rather than integrated manner. The Ontosemiotic Approach proposed in this article does not seek to replace these constructs but to articulate them within a unified analytical framework that makes explicit the organization of activity, the emergence of meaning, and the ontological structure of semiosis in living systems.

Before introducing the Ontosemiotic Approach in detail, it is important to emphasize that its application to biological systems is strictly analytical. The framework is used to describe the organization of activity and meaning in living agents without attributing human-like cognition, deliberation, or symbolic reasoning to them. Its aim is to provide conceptual categories for analyzing how organisms interpret and act upon signs within their ecological contexts, rather than to anthropomorphize biological behavior.

3. Ontosemiotic Approach to Activity, Meaning, and Cognition

The Ontosemiotic Approach (OSA) was originally developed within the field of mathematics education as a theoretical and methodological framework for analyzing the emergence of meaning, knowledge, and objects from problem-solving activity (Godino, 2004; Godino et al., 2007). Drawing on pragmatist semiotics, sociocultural theory, and philosophical anthropology, the Ontosemiotic Approach conceives meaning not as an intrinsic property of representations but as a relational construct arising from situated activity (Peirce, 1931–1958; Vygotsky, 1978; Wittgenstein, 1953). Although its initial domain of application was human mathematical practice, the OSA articulates a general ontology of activity, meaning, and cognition that can be extended—at an analytical level—to other forms of autonomous agency, including biological systems.

From a biosemiotic perspective, the relevance of the OSA lies in its capacity to articulate, within a unified framework, ecological context, problematic situations, practices, semiotic processes, and the objects that emerge from them. Rather than focusing exclusively on the structure of signs or codes, the OSA foregrounds activity as the generative locus of semiosis, thereby aligning with biosemiotic conceptions of life as sign-guided action.

3.1. Ontological Model of Activity

At the core of the Ontosemiotic Approach is an ontological model that conceives activity as a structured response to problematic situations within a given context (Figure 1). Any activity is initiated by a problem—explicit or implicit—that demands resolution and mobilizes a repertoire of practices. These practices are always situated: they unfold within ecological, material, institutional, or biological constraints that shape what can be perceived, interpreted, and done.

Fig. 1 Ontosemiotic configuration

The sequence of practices implemented to resolve a specific type of problem constitutes the process of problematization, through which the problem is generated and mobilized as a primary object. The remaining *primary objects*—languages, concepts, propositions, procedures, and arguments—likewise emerge from their respective processes of communication, definition, enunciation, algorithmization, and argumentation, which are themselves understood as sequences of practices. These objects are not conceived as abstract entities detached from action, but as semiotically constituted elements that organize and coordinate activity (Font et al., 2013).

The ontological model is further enriched by a system of five dualities—expression/content, exemplar/type, unitary/systemic, ostensive/non-ostensive, and personal/institutional—which allow the identification of *secondary processes* such as representation, generalization, decomposition, idealization, and institutionalization. These dualities capture fundamental tensions inherent in any semiotic activity and provide analytical tools for examining how meaning stabilizes, transforms, and circulates across contexts.

When transposed to biosemiotics, this ontological model allows biological activity to be described as a network of semiotically mediated practices oriented toward resolving ecological problems. Importantly, this transposition does not attribute symbolic reasoning or reflective intentionality to organisms; rather, it provides a vocabulary for analyzing how meaning emerges from embodied interaction with the environment.

3.2. Semiotic Functions and the Structure of Meaning

A central construct of the Ontosemiotic Approach is the notion of *semiotic function*, which provides a general theory of meaning integrating referential, operational, and pragmatic dimensions. A semiotic function is defined as a correspondence established between an antecedent object (expression /signifier)) and a consequent object (content /meaning) by a subject—individual or collective—according to a rule or code of interpretation (Godino et al., 2021).

This definition generalizes the Peircean notion of the sign while preserving its triadic structure. Any entity involved in activity—linguistic or non-linguistic, material or immaterial, unitary or systemic—can function as an expression or a content. Consequently, meaning—understood as the content of any semiotic function—is not

restricted to lexical elements or symbolic representations; rather, it extends to procedures, perceptual patterns, ecological relationships, and action schemes.

In the OSA, the meaning of an object is inherently contextual and practice-dependent. The content of a semiotic function often consists not of a single referent but of a system of practices associated with a class of problems in specific contexts. These partial meanings, generated across diverse situations, collectively constitute the *holistic meaning* of the object. This pragmatic conception of meaning resonates strongly with biosemiotic accounts in which signs acquire significance through their functional role in guiding action.

By emphasizing correspondence, context, and practice, the notion of semiotic function extends biosemiotic analyses of biological codes. It allows not only molecular correspondences but also perceptual cues, environmental affordances, and behavioral regularities to be treated as meaningful relations structured by interpretation.

3.3. Ontosemiotic Perspective on Cognition

The Ontosemiotic Approach to cognition emerged from the need to reconcile individual and collective dimensions of knowledge. It distinguishes between *personal meanings*, which correspond to the semiotic functions established by an individual agent, and *institutional meanings*, which correspond to historically stabilized systems of practices shared within a community (Godino & Batanero, 1998). Cognition, in this framework, is not a purely internal process but a semiotically mediated capacity to act effectively within a domain of problems. This approach aligns with traditions in both cognitive semiotics (Zlatev, 2012; Paolucci, 2021) and cultural semiotics (Eco, 1976; Lotman, 1990).

Understanding, from an ontosemiotic perspective, consists in establishing and coordinating semiotic functions among objects. Each semiotic function constitutes an act of semiosis and, simultaneously, a unit of knowledge. Knowledge is thus distributed across networks of semiotic functions that integrate perception, memory, action, and evaluation. Importantly, the contents of these functions may include systems of practices, thereby incorporating the pragmatic dimension of "knowing how" alongside propositional or representational aspects.

This conception of cognition aligns with enactive and ecological approaches, according to which cognition is fundamentally action-oriented (Lakoff & Núñez, 2000). It also resonates with biosemiotic models that view organisms as anticipatory agents whose cognitive capacities are expressed through sign-guided interaction with the environment (Hoffmeyer, 2008; Sharov, 2010).

Within this framework, cognition is not limited to the interpretation of external signs but involves an ontology of objects—both ostensive and non-ostensive—that "furnish the world" of the agent (Bunge, 1977). Individual cognition is therefore inseparable from the organism's capacity to solve problems and maintain itself within a changing environment, reinforcing the view of cognition as an emergent property of semiotically structured activity.

3.4. Ontosemiotic Method for Analyzing Activity

The ontosemiotic method provides a structured procedure for analyzing activity through three complementary levels (Figure 2):
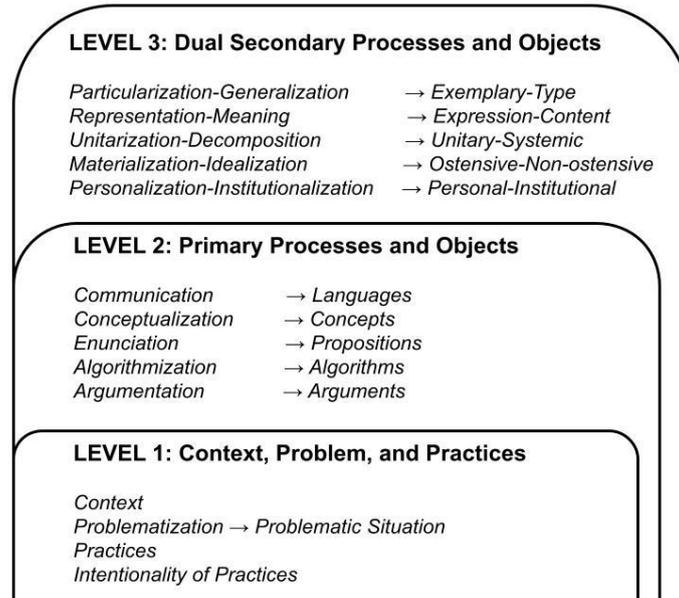
Fi. 2 Levels of comprehensive ontosemiotic analysis

Level I: Context, problem, and practices, focusing on the ecological or situational conditions of activity, the problematic situations that motivate action, and the practices deployed in response.

Level II: Primary processes and objects, identifying the semiotic processes and objects (languages, concepts, propositions, procedures, arguments) that emerge within the activity.

Level III: Secondary processes and objects, analyzing how these primary objects are transformed through dualities such as generalization/particularization, representation/signification, or individualization/communitarization.

This multi-level framework allows activity to be examined at different scales, from micro-level interactions to more global organizational patterns, without fragmenting the analysis. Crucially, the ontological dimension is not treated as an external add-on but as the organizing axis of the method: activity is understood as a semiotically articulated network of objects and processes.

In the context of biosemiotics, this method offers a way to make explicit the internal organization of biological semiosis. It provides analytical categories for examining how ecological problems are constituted, how organisms mobilize semiotic resources to address them, and how meaning stabilizes through interaction with the environment. In the following section, this methodological framework is applied to a concrete biological case: the hunting activity of the red fox.

4. Case Study: An Ontosemiotic Analysis of Fox Hunting Activity

To illustrate the applicability of the Ontosemiotic Approach (OSA) to biological systems, this section analyzes the hunting behavior known as *mousing* in the red fox (*Vulpes vulpes*), with reference to comparable strategies described for the Arctic fox (*Vulpes lagopus*) in classical ethological studies (Henry, 1996; Zimen, 1980). This predatory activity is particularly characteristic of winter environments in which prey is concealed

beneath snow, rendering visual detection ineffective and foregrounding auditory and proprioceptive cues.

From a biosemiotic standpoint, fox hunting constitutes a paradigmatic case of individual-level semiosis embedded in an ecosystem. The fox interprets a heterogeneous set of environmental signs—sounds, substrate resistance, wind direction—and coordinates them within a functional cycle oriented toward prey capture. This activity thus provides a suitable empirical domain for examining how meaning, action, and cognition emerge from the interaction between an autonomous biological agent and its ecological context.

The ontosemiotic analysis follows the three analytical levels introduced in Section 3. The present section focuses on Level I, describing the ecological context, the problematic situation motivating the activity, and the sequence of practices through which the fox responds. This level establishes the situational foundation for the semiotic objects and processes analyzed subsequently.

4.1. Level I: Context, Problem, and Practices

At Level I, hunting is examined as a situated activity organized around a biologically significant problem and enacted through a coordinated sequence of practices. The goal is not to ascribe reflective cognition to the fox, but to describe how ecological conditions, internal states, and environmental cues jointly structure a field of meaningful action.

This level addresses three components:
(1) the ecological and sensory context;
(2) the problematic situation constituted through problematization; and
(3) the sequence of practices mobilized in response.

4.1.1. Ecological and Sensory Context

In the Ontosemiotic Approach, *context* refers to the situational conditions that constrain and enable activity. In biological systems, this notion is refined by Jakob von Uexküll's distinction between *Umgebung* (the objective environment) and *Umwelt* (the organism's species-specific world of significance). The fox inhabits an Umwelt in which certain environmental features function as meaningful signs relative to its sensory capacities and biological needs.

In snow-covered environments, visual cues are largely unavailable, and the ecological context is semiotically reorganized. Auditory signals, substrate resistance, wind direction, and geomagnetic cues become dominant sources of meaning. Empirical evidence indicates that foxes integrate acoustic information with geomagnetic orientation to localize prey beneath the snow (Červený et al., 2011), and execute a specialized pouncing leap optimized for vertical penetration of the snow crust (Henry, 1996).

From an ontosemiotic perspective, the context is not a passive background but an active component of semiosis. Snow, sound, and terrain function as expressive media that shape the fox's interpretive activity, constituting a semiotically structured Umwelt.

4.1.2. The Problematic Situation Motivating the Activity: Problematization

In the OSA, a *problem* is the generative core of activity. It does not exist independently of the agent but emerges through a process of *problematization*, whereby a situation is interpreted as requiring resolution. In biological systems, problems are not linguistically formulated but arise as tensions between internal states and environmental affordances.

In the fox, this tension is driven by energetic needs under conditions of prey concealment and perceptual uncertainty. Hunger functions as an internal sign activating foraging behavior and orienting attention toward relevant environmental cues. Environmental signals—faint sounds, vibrations, scent traces—are interpreted in relation to this internal state, giving rise to a functional challenge: obtaining food under constrained perceptual conditions.

The problematic situation is dynamic rather than static. Variations in prey movement, snow density, wind, or competition continuously reshape the field of action, triggering re-problematization and adjustment of practices. Problematization thus transforms a diffuse ecological situation into an operative challenge by selecting relevant signs, delimiting probable prey locations, and orienting behavior toward resolution.

4.1.3. Sequence of Practices

Within the Ontosemiotic Approach, *practices* are coordinated actions—linguistic or non-linguistic—performed to address a problem. In non-human autonomous agents, practices correspond to structured patterns of perception, inference, and motor execution oriented toward biological viability.

Fox hunting can be described as a sequence of interrelated practices (Henry, 1996) (Figure 3):
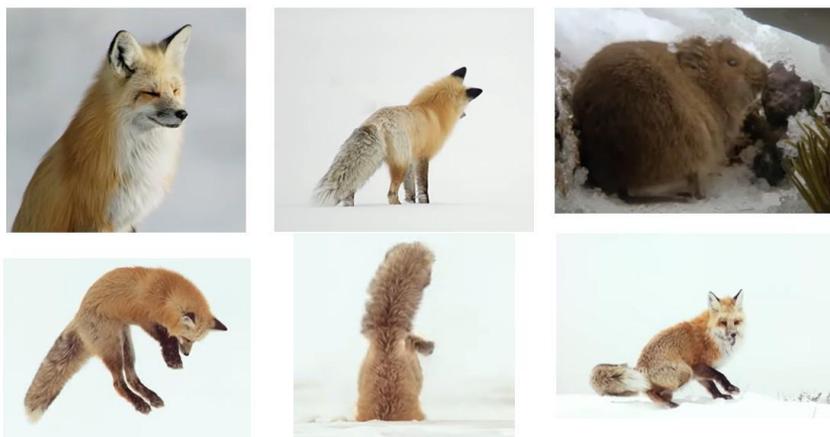

Fig. 3 Sequence of practices in fox hunting activity (mousing), illustrated through six representative frames corresponding to successive phases of the hunting process. The images are screenshots derived from a publicly accessible National Geographic video available on YouTube [https://www.youtube.com/watch?v=EfnVdHlL238]). The frames are reproduced solely for scholarly analysis and non-commercial academic use.

1. *Perceptual exploration:* systematic scanning through olfaction, audition, and vision to detect relevant cues.
2. *Inferential localization:* integration of multisensory signals to estimate prey presence and position beneath the snow, exemplifying action-guiding semiosis (Sharov & Tønnessen, 2021).
3. *Strategic approach:* silent repositioning relative to wind and terrain, coupled with embodied anticipation of the attack trajectory.
4. *Operational attack:* execution of a specialized parabolic pounce guided primarily by auditory information.
5. *Feedback and adjustment:* reassessment and repetition of actions when initial attempts fail.

6. *Closure:* capture, killing, and consumption or storage of prey, temporarily resolving the problematic situation.

At Level I, these practices constitute the observable organization of the hunting activity and provide the situational basis for identifying the primary semiotic objects and processes analyzed at Level II.

4.2. Level II: Primary Objects and Processes

At Level II, the ontosemiotic analysis focuses on the *primary semiotic processes* and the *primary objects* that emerge from the hunting activity described at Level I. Whereas Level I addressed the situational organization of the activity, Level II examines how meaning is constituted through semiotic functions linking perceptual cues, actions, and ecological relations within the fox's Umwelt.

In the Ontosemiotic Approach, primary objects are semiotically stabilized entities that arise from fundamental processes of activity (Font et al., 2013). Although the OSA was originally formulated to analyze human practices and distinguishes families such as concepts, procedures, propositions, and arguments, its analytical structure can be adapted to biological systems by interpreting these objects in non-linguistic, embodied, and functional terms. At this level, the analysis does not presuppose symbolic reasoning but identifies recurrent semiotic regularities that guide action.

4.2.1. Primary Semiotic Processes in Fox Hunting

The hunting activity of the fox involves a network of semiotic processes through which environmental cues acquire meaning relative to the agent's biological goals. These processes include perception, discrimination, association, anticipation, and procedural execution. Together, they constitute a semiotically mediated cycle transforming ecological signals into coordinated action.

Auditory perception plays a central role: faint sounds generated by prey movement beneath the snow function as expressions within a semiotic function whose content concerns prey location, depth, and movement. These auditory signs are not interpreted in isolation but are integrated with olfactory cues, proprioceptive feedback, and geomagnetic orientation. The semiotic process thus involves multisensory integration governed by learned regularities and embodied constraints (Deacon, 2021).

Crucially, these processes are normative rather than purely causal. Certain cues are treated as relevant, others as noise, depending on their functional value for prey detection. This selective sensitivity exemplifies what biosemiotics characterizes as value-based semiosis, in which signs matter insofar as they contribute to the organism's viability (Hoffmeyer, 2008). From an ontosemiotic perspective, the semiotic processes of hunting instantiate stable correspondences between environmental expressions and action-guiding contents.

4.2.2. Primary Objects as Semiotic Regularities

Within this network of semiotic processes, several primary objects can be analytically identified. These objects are not mental representations but stabilized semiotic regularities that organize activity through practice. In ontosemiotic terms, they correspond to the stabilized contents of semiotic functions enacted in problem-oriented activity, rather than to abstract entities or internal cognitive states (Godino, Batanero, & Font, 2007; Font et al., 2013).

One such object is the *prey-as-located-beneath-snow*, constituted through the semiotic integration of auditory depth cues, sound intensity, and spatial orientation. This object is not directly perceived but inferred through sign-mediated processes: ostensive acoustic cues function as expressions whose content concerns a non-ostensive object, namely the position and accessibility of prey beneath the snow. This inferential structure exemplifies the Peircean conception of semiosis as a triadic relation in which meaning arises through interpretation rather than through direct perception (Peirce, 1931–1958).

Another primary object is the *pouncing trajectory*, understood as a procedural object specifying the coordinated motor pattern required to penetrate the snow crust and immobilize prey. This object is not the result of explicit calculation but emerges from the repeated coordination of bodily capacities and environmental constraints within hunting practice. As a stabilized procedural invariant, it organizes action by delimiting what counts as an appropriate or ineffective attack within the ecological context.

Additional primary objects include zones of ecological relevance (areas where prey is likely to be present), action thresholds (conditions under which the fox commits to an attack), and failure indicators (signs prompting reassessment and repetition of practices). These objects function as semiotically constituted criteria that structure the hunting activity by regulating the transition between exploratory, operative, and evaluative phases.

Taken together, these primary objects constitute a functional ontology of the hunting activity. They are neither symbolic representations nor abstract categories but pragmatic-semiotic invariants that coordinate perception and action across situations. Their stability lies in their role within recurrent semiotic functions enacted through practice, illustrating how meaning in biological systems is organized through structured regularities of sign-guided activity rather than through internal representations.

4.2.3. Semiotic Functions in the Hunting Activity

The notion of semiotic function provides a unifying framework for analyzing how the primary objects identified above emerge and operate within the hunting activity. In fox hunting, semiotic functions establish context-sensitive correspondences between expressive elements—such as sounds, vibrations, or substrate resistance—and operative contents, including prey localization, depth estimation, and readiness for action.

For example, a specific acoustic pattern functions as an expression whose content is the estimated position of prey beneath the snow. This correspondence is not reducible to a fixed stimulus–response relation but is enacted through biologically stabilized interpretive regularities shaped by evolutionary history and individual learning. The meaning of the acoustic signal lies not in its physical properties alone but in its capacity to guide appropriate action within a specific ecological context, exemplifying semiosis as an interpretive process rather than a direct perceptual mapping.

Importantly, the same expression may participate in different semiotic functions depending on contextual conditions. A sound may function as a prey indicator, a competitor signal, or irrelevant noise depending on its temporal, spatial, and relational features. Meaning is therefore context-dependent and dynamically constituted through activity, in line with both ontosemiotic and biosemiotic principles.

From this perspective, the analysis extends biosemiotic accounts of biological codes by emphasizing not only correspondence but also contextualized function. While code-based models focus on stabilized mappings between domains, semiotic functions in hunting are embedded in broader networks of practices and ecological constraints, rather

than operating as isolated coding relations (Barbieri, 2008). Meaning thus emerges through the coordinated organization of sign-guided activity rather than through decontextualized rules.

4.2.4. Primary Processes as Non-Linguistic Meaning-Making

From an ontosemiotic perspective, the primary processes identified here instantiate a form of non-linguistic meaning-making. Meaning emerges through the successful coordination of semiotic functions within the activity cycle, rather than through symbolic representation or conscious deliberation. In this sense, semiosis is enacted as a practical achievement embedded in ongoing activity, consistent with the Peircean conception of meaning as arising from interpretive relations rather than from mental contents (Peirce, 1931–1958).

The fox's hunting behavior thus exemplifies embodied semiosis: signs are enacted through bodily engagement with the environment, and their interpretation is inseparable from motor execution and ecological context. Sounds, vibrations, and resistances function as meaningful signs insofar as they guide action relevant to the organism's viability. Meaning is therefore not located within internal mental states but at the dynamic interface between organism and environment, in line with core biosemiotic accounts of sign-guided action (Hoffmeyer, 2008).

At Level II, the analysis shows how hunting activity gives rise to a structured semiotic domain composed of primary objects and processes. These elements constitute the functional substrate of meaning-making and provide the foundation for the more abstract and relational objects examined at Level III, where secondary processes such as generalization, stabilization, and the formation of ecological norms will be analyzed.

4.3. Level III: Dual Secondary Objects and Processes

Level III of the ontosemiotic analysis focuses on secondary objects and secondary semiotic processes that emerge through the stabilization, transformation, and coordination of the primary objects identified at Level II. Whereas primary objects arise directly from situated activity, secondary objects result from semiotic operations that organize meaning across contexts, situations, and temporal scales. In ontosemiotic terms, these processes are structured by a system of dualities that articulate how meaning stabilizes and circulates beyond individual episodes of activity.

Although originally formulated for the analysis of human practices, these dualities can be analytically extended to biological systems when interpreted in non-linguistic and non-anthropomorphic terms. At this level, the analysis reveals how individual hunting episodes participate in more general semiotic structures that regulate behavior over time.

4.3.1. Expression / Content Duality

The expression/content duality distinguishes between the perceptible or operative elements that function as signs (expressions) and the functional meanings they convey (contents). In fox hunting, expressions include acoustic cues, vibrations, substrate resistance, and spatial orientation signals, while contents consist of action-relevant meanings such as prey presence, depth, direction, and feasibility of attack.

This duality is dynamically enacted rather than fixed. The same physical expression may correspond to different contents depending on contextual conditions, such as wind direction, snow density, or prey behavior. Meaning is therefore not intrinsic to expressions

but emerges through interpretive activity situated within the fox's Umwelt, in line with Peirce's conception of the sign as a context-sensitive triadic relation (Peirce, 1931–1958).

4.3.2. Ostensive / Non-Ostensive Duality

The ostensive/non-ostensive duality concerns the distinction between objects that are directly perceptible and those that are not perceptually available but are nevertheless semiotically operative. In the hunting scenario, prey beneath the snow constitutes a non-ostensive object: it is not directly visible but is inferred through ostensive cues such as sounds, vibrations, or surface irregularities.

The fox's activity involves the continual coordination of ostensive expressions with non-ostensive contents. Successful hunting depends on maintaining and updating this coordination as environmental conditions change. This inferential structure exemplifies a core Peircean insight: that semiosis routinely involves reference to objects that are not immediately given in perception (Peirce, 1931–1958).

4.3.3. Unitary / Systemic Duality

The unitary/systemic duality distinguishes between objects treated as indivisible units and those understood as structured systems of relations. In fox hunting, an isolated sound may function as a unitary object triggering a rapid response, whereas a complex prey-signature—comprising multiple sounds, temporal patterns, and spatial relations—functions as a systemic object guiding coordinated action.

This duality allows the analysis to capture different levels of semiotic organization. Unitary objects support fast, local decisions, while systemic objects enable anticipatory and integrative practices. The capacity to shift between these modes reflects a flexible semiotic competence shaped by ecological demands and reinforced through repeated activity (Sharov, 2010).

4.3.4. Particular / General Duality

The particular/general duality concerns the relation between individual instances of activity and generalized semiotic regularities. Each hunting episode is a particular event, yet it is guided by generalized expectations regarding prey behavior, snow conditions, and effective attack strategies.

These generalities are not abstract rules but stabilized habits of interpretation and action acquired through evolutionary history and individual experience. From a Peircean perspective, such habits constitute genuine semiotic generality, grounding meaning in recurrent patterns of successful action rather than in explicit representations (Peirce, 1931–1958).

4.3.5. Personal / Ecological (Institutional) Duality

In the Ontosemiotic Approach, the personal/institutional duality distinguishes between individual meanings and meanings stabilized within a community or institution. In biological systems, this duality can be reinterpreted as a distinction between individual-level semiotic functions and ecologically stabilized semiotic structures.

In fox hunting, individual variation in technique and success coexists with species-typical patterns shaped by evolutionary and ecological constraints. The ecological niche functions analogously to an institution by stabilizing certain semiotic functions—such as prey localization strategies—across individuals and generations. This stabilization reflects what biosemiotics characterizes as ecological normativity, whereby meanings are

evaluated implicitly through their contribution to biological viability (Hoffmeyer, 2008; Sharov & Tønnessen, 2021).

4.3.6. Secondary Processes and Semiotic Stabilization

The dualities discussed above give rise to secondary semiotic processes such as generalization, differentiation, stabilization, and reconfiguration of meaning. Through these processes, primary objects are integrated into broader semiotic structures that regulate behavior beyond individual episodes.

In fox hunting, repeated coordination of perceptual cues and actions leads to the stabilization of effective semiotic functions, while ineffective correspondences are gradually discarded. These dynamics exemplify biological normativity: meanings persist insofar as they contribute to successful action and organismal viability (Hoffmeyer, 2011). At Level III, the ontosemiotic analysis thus reveals how individual acts of semiosis participate in higher-order semiotic organization without invoking internal representations or symbolic reasoning.

5. Comparison with Other Formalization Efforts in Biosemiotics

Over the past decades, biosemiotics has produced several formalization efforts aimed at clarifying the conceptual foundations of semiosis in living systems. These approaches differ in scope, methodology, and ontological commitments, but share the goal of articulating biological organization in semiotic terms. In this section, we situate the Ontosemiotic Approach (OSA) with respect to some of the most influential formal frameworks in biosemiotics, highlighting points of convergence, divergence, and complementarity.

The comparison does not seek to establish the OSA as a competing or replacement theory. Rather, it aims to show how the OSA can function as a meta-analytical framework capable of integrating and clarifying existing biosemiotic models by making explicit the organization of activity, meaning, and objects across different analytical levels.

5.1. Peircean and Peirce-Inspired Formalizations

Many formalization efforts in biosemiotics are grounded in Peirce's triadic model of the sign and in the logic of semiosis as an open-ended interpretive process. These approaches emphasize the irreducibility of the sign relation and the central role of the interpretant in biological meaning-making (Queiroz el al., 2010; Hoffmeyer, 2008). Formal tools derived from Peircean semiotics have been used to model cellular signaling, behavioral communication, and evolutionary dynamics of sign systems.

The Ontosemiotic Approach is fully compatible with this tradition, as it also conceives semiosis as a relational and triadic process. However, while Peirce-inspired models primarily focus on the internal structure and dynamics of sign relations, the OSA places analytical priority on *activity* as the generative locus of semiosis. Semiotic relations are not treated in isolation but are situated within problem-oriented practices unfolding in ecological contexts.

In this sense, the OSA complements Peircean formalizations by providing categories for analyzing how signs are mobilized within concrete activities and how semiotic functions are stabilized through repeated action. The emphasis shifts from the abstract logic of signs to the organization of sign-guided practices.

5.2. Code-Based and Information-Theoretical Models

Another influential line of formalization in biosemiotics centers on biological codes and information-theoretical frameworks. Barbieri's theory of biological codes offers a rigorous account of how symbolic correspondences arise in living systems through adaptor-mediated rules (Barbieri, 2008, 2024). Similarly, information-theoretical approaches analyze biological communication in terms of signal transmission, constraint, and organization (Deacon, 2021).

These models provide valuable insights into the structural and regulatory aspects of biological semiosis, particularly at molecular and cellular levels. However, they often abstract away from the situated activity in which codes and signals acquire functional relevance. The Ontosemiotic Approach addresses this limitation by embedding correspondences within broader activity systems that include problems, practices, and ecological constraints.

From an ontosemiotic perspective, biological codes can be interpreted as stabilized semiotic functions whose meaning is realized through their role in guiding action. The OSA thus does not challenge code-based models but extends them by situating codes within the dynamics of organism–environment interaction and by clarifying how coded relations participate in multi-level semiotic organization.

5.3. Ecological and Agency-Oriented Frameworks

Several biosemiotic formalizations emphasize the role of agency, embodiment, and ecological embeddedness in semiosis. Concepts such as *semiotic agency* (Sharov, 2010; Hoffmeyer, 2013), *semiotic scaffolding* (Hoffmeyer, 2008), and *eusemiosis* (Sharov & Tønnessen, 2021) foreground the idea that organisms actively interpret signs in order to maintain themselves within their environments.

The Ontosemiotic Approach aligns closely with these perspectives by conceptualizing living systems as autonomous agents engaged in problem-solving activities. Its emphasis on practices and problematization resonates with ecological and enactive accounts of cognition, while its ontological framework provides analytical categories for distinguishing different types of semiotic objects and processes.

What the OSA adds to agency-oriented frameworks is a systematic multi-level structure that allows the analysis of semiosis to move coherently from situated action (Level I) to stabilized meaning structures (Levels II and III). This structure facilitates comparisons across organisms, contexts, and scales without reducing semiosis to either internal cognition or external signaling alone.

5.4. Formal Ontologies and Systems-Theoretical Approaches

Some formalization efforts in biosemiotics draw on systems theory and formal ontology to model biological organization. Approaches inspired by autopoiesis, anticipatory systems, and hierarchy theory seek to capture the self-organizing and self-maintaining character of living systems (Maturana & Varela, 1980; Rosen, 1985).

While these frameworks offer powerful descriptions of biological organization, they often lack explicit tools for analyzing meaning and signification as semiotic phenomena. The Ontosemiotic Approach contributes to this domain by explicitly integrating ontological analysis with semiotic functions, thereby linking system organization with meaning-making processes.

In this respect, the OSA can serve as a bridge between systems-theoretical models and semiotic analyses, providing a vocabulary for describing how systemic constraints and semiotic relations co-constitute biological activity.

5.5. Comparative Assessment and Integrative Potential

Across these diverse formalization efforts, a common challenge remains: articulating biological processes and semiotic processes within a unified analytical framework that preserves both causal and interpretive dimensions. The Ontosemiotic Approach addresses this challenge by offering a structured ontology of activity that integrates context, problem, practice, semiotic function, and object.

Rather than proposing a new foundational theory of biosemiotics, the OSA functions as an integrative and clarifying framework. It allows existing models to be positioned within a common analytical space and facilitates dialogue between code-based, Peircean, ecological, and systems-theoretical approaches.

The comparative analysis suggests that the primary contribution of the OSA lies in its capacity to make explicit the organization of semiosis as an activity-based and multi-level phenomenon. This contribution is particularly relevant for biosemiotics, where theoretical plurality is a strength but also a source of conceptual fragmentation.

6. Conclusions and Future Perspectives

This article has proposed the Ontosemiotic Approach (OSA) as a complementary analytical framework for biosemiotic research, aimed at clarifying how meaning, action, and cognition are organized in living systems. By foregrounding activity as the generative locus of semiosis, the OSA provides conceptual tools for articulating ecological context, problematic situations, practices, and semiotic objects within a unified ontological structure.

The case study of fox hunting activity illustrates how this framework can be applied to biological phenomena without attributing symbolic reasoning or reflective intentionality to non-human organisms. Through the three analytical levels—context and practices (Level I), primary objects and processes (Level II), and secondary objects and dual processes (Level III)—the analysis shows how semiosis emerges from embodied interaction with the environment and stabilizes through recurrent patterns of sign-guided activity. Meaning, in this perspective, is neither subjective nor representational but functional, ecological, and value-based.

A central contribution of the OSA to biosemiotics lies in its explicit treatment of *semiotic function* as a correspondence established in and through practice. This notion extends existing biosemiotic accounts of biological codes and sign relations by situating them within concrete activity systems and by making explicit the contextual conditions under which correspondences acquire meaning. In doing so, the OSA bridges gaps between Peircean semiotics, code-based models, ecological approaches, and systems-theoretical perspectives.

Importantly, the Ontosemiotic Approach does not seek to replace established biosemiotic theories. Rather, it functions as a meta-analytical framework that facilitates conceptual integration and comparative analysis across different formalization efforts. Its strength lies in providing a structured vocabulary for describing how biological semiosis is organized across multiple levels, from immediate perception–action coupling to more stabilized ecological and evolutionary regularities.

Several avenues for future research follow from this work. First, the ontosemiotic framework can be applied to a broader range of biological activities, including collective behaviors, interspecific communication, and developmental processes, to assess its

generality and limitations. Second, further work is needed to explore the relation between ontosemiotic levels and evolutionary timescales, particularly regarding the emergence and stabilization of semiotic norms. Third, the integration of the OSA with empirical research in ethology, ecology, and systems biology offers promising opportunities for developing analytically rigorous yet biologically grounded models of meaning.

More broadly, this study supports the view that biosemiotics benefits from frameworks capable of articulating biological and semiotic explanations without reducing one to the other. By making explicit the ontological organization of semiosis in living systems, the Ontosemiotic Approach contributes to the ongoing effort to understand life not merely as a set of biochemical processes, but as a dynamic and meaning-laden mode of existence.

Declarations

Conflict of interest. The author did not receive funding from any sources to prepare this manuscript and has no conflict of interest to declare. No data was produced during this research.

Use of AI statement

In preparing this article, artificial intelligence tools were employed to suggest translations and refine wording for clarity and precision. AI was not involved in conceptualizing research goals and methodology. All AI-revised content was critically reviewed to ensure accuracy and alignment with the intended meaning and objectives of the work.

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