Phenomenology and the Cognitive Sciences
https://doi.org/10.1007/s11097-024-10013-y

Nonveridical biosemiotics and the Interface Theory of Perception: implications for perception-mediated selection

Brian Khumalo[1] · **Yogi Hale Hendlin**[2,3]

Accepted: 19 July 2024

Abstract

Recently, the relationship between evolutionary ecology and perceptual science has received renewed attention under perception-mediated selection, a mode of natural selection linking perceptual saliency, rather than veridicality, to fitness. The Interface Theory of Perception (ITP) has been especially prominent in claiming that an organism's perceptual interface is populated by icons, which arise as a function of evolved, species-specific perceptual interfaces that produce approximations of organisms' environments through fitness-tuned perceptions. According to perception-mediated selection, perception and behavior calibrate one another as organisms' capacities to experience and know the objects and properties of their environments lead to responses highlighting certain environmental features selected for survival. We argue this occurs via the *Umwelt*/*Umgebung* distinction in ethology, demonstrating that organisms interact with their external environments (*Umgebung*) through constructed perceptual schema (*Umwelt*) that produce constrained representations of environmental objects and their properties. Following Peircean semiotics, we claim that ITP's focus on icons as saliency-simplified markers corresponds to biosemiotics' understanding of perceptual representations, which manifest as iconic (resembling objects), indexical (referring), or symbolic (arbitrary) modalities, which provide for organisms' semiotic scaffolding. We argue that ITP provides the computational evidence for biosemiotics' notion of iconicity, while biosemiotics provides explanation within ITP for how iconicity can build up into indices and symbols. The common contention of these separate frameworks that the process of perception tracks saliency rather than veridicality suggests that digital/dyadic perceptual strategies will be outcompeted by their semiotic/triadic counterparts. This carries implications for evolutionary theory as well as theories of cognition.

Keywords Biosemiotics · Indirect realism · Interface theory of perception · Veridicality and nonveridicality · Abduction · Perception-mediated selection

---

Extended author information available on the last page of the article

1 Introduction

Perception and behavior are interlinked because an organism's capacity to experience and know environmental objects and their properties leads to responses reflecting features salient for survival (Brown, 1992). Historically, some researchers (e.g., Boring, 1936; Palmer, 1999; Wilson, 2001) have claimed that accurate perceptual representations depend on an isomorphic relationship between object representation and the perceived object, characterized by a bijection that preserves structure and operations (Rupnow, 2021). Hoffman et al's (2015) Interface Theory of Perception (ITP) disputes these claims, proposing instead that an organism's perceived reality (*Umwelt*) is a functional approximation of its external reality (*Umgebung*) (Hoffman, 2016; Prakash et al., 2020a, b). Function serves immediate aims, and accounts for the pragmatic, salient pressures of evolution outstripping the efficacy of exhaustively knowing and responding to all possible facts of objects in their complexity. Saliency is paramount to facilitating action, rejecting one-to-one *Umwelt/Umgebung* congruent structures as neither possible nor preferable. This suggests, however, that representational functionality requires the existence of the organism-plus-environment unit to provide meaningful context. According to this pragmatic saliency model, perceptual veridicality – a perceiver-perceived dyad – would be evolutionarily uncompetitive compared to perceptual nonveridicality because the excess effort spent understanding and acting on unproductive facts would be debilitating.

We propose that the nonveridical Interface Theory of Perception affirms a triadic perceptual relationship involving the perceiving organism, perceived object, and the subjectively perceived representation of the object, mirroring Peircean semiotics (e.g., Sebeok, 1980; Sharov, 1992; Deely, 2001a). By extension, we agree with Hoffman et al. (2015) that all currently living organisms construct reality nonveridically. The ITP shares many other features with the phenomenology-informed theoretical biology of Jacob von Uexküll (Barbieri, 2020). In our view, organisms construct their *Umwelten* by way of species-specific, fitness-tuned perceptual interfaces they have been gifted through evolutionary processes which simplify external complexity for survivability. Significance in biosemiotics, and saliency for the ITP, point at similar perceptual selection functions. We hold that the ITP contributes to biosemiotics by providing computational evidence that iconic representations manifest from fitness-tuned contact between an organism's sense perceptions and the external environment. Biosemiotics likewise contributes to the ITP through explaining how these iconic representations contextualize (scaffold into) indices and symbols, together forming the three fundamental modalities of perceptual representation (Favareau, 2015).

2 Objects of perception

Perception requires that an organism experience environmental objects and their properties through sense-data (Brier, 2008). Various perceptual theories assume perception is veridical (e.g., Marr, 1982; Palmer, 1999; Pizlo et al., 2014), a dyadic perceiver/perceived object relation given the logical operation: F is veridical iff Fp entails p, or simply, Fp → p[1] (Giannakidou, 1998). Dyadic perceptions, as proposed, function similarly to Saussurean signifier-signified sign relationships whereby the smallest units of psycholinguistic meaning spawn from dyadic sign relations (de Saussure, 2004). Dyadic perceptual strategies reinforce direct realism (naïve or commonsense realism), the view that perception entails 1:1 correspondence between what is experienced and known (epistemology) and what is (ontology). Consequently, meaning-making only requires: (1) a perceiver and, (2) the directly perceived object. We are sympathetic to realism[2], however, we reject dyadic perception because it lacks an ontic referent (Hoffmeyer, 1993; Sharov, 2010; Cobley, 2016). Dyadic perceptions decay into extreme reductionism evident in forms of realism, and extreme subjectivism evident in forms of idealism due to the lack of an ontic referent (Hoffman et al., 2015). In place we suggest a Peircean triad, composed of signifier-signified-object sign relations (Sebeok, 2001). Peircean perception retains realism, while necessitating that meaning-making is contingent, occurring indirectly (representational realism) requiring: (1) a perceiver, (2) an external object that is perceived indirectly and, (3) a subjective representation that is perceived directly (Brown, 1992). Perception influences behavior – an organism's actions toward its *Umwelt*, seeking to adapt to the conditions of the *Umgebung* while only being aware of a small part of it (von Uexküll, 1926; Piaget, 1979). Behaviorally, a Peircean model describes the organism-plus-environment unit as a relational unit where organisms as active agents shape and are shaped by their environments. Perception maximizes the organism's life history requirements within its environmental niche, the conditions and resources required for organisms to live, grow, mature, and reproduce (Figueredo et al., 2006).

3 Realism and veridicality: dyadic or triadic?

Indirect realism entails that knowledge of the world arises from access only to a perceptual copy of its properties and features as bounded by the senses (Deely, 2001b).[3] Knowledge develops from cumulative experiences of environmental objects and their properties (Brown, 1992). If we designate the experiencing organism as the interpretant, the ontic referent as the Peircean object, and the subjective representation of the ontic referent as the representamen (features of the object imputed as relevant and available for the interpretant) (Hoffmeyer, 1993), an ethological description of the *Umwelt/Umgebung* emerges. Interpretants perceive (*Umwelten*) because they experience features of their *Umgebung* nonveridicality through a differentiation of object representations and the objects themselves. Direct, veridical perceptual strategies do not make this differentiation. Thus direct, veridical perception cannot be true because sense-data as interpretive schema are always bounded by physiological and psycho-

---

[1] Not all scholars agree with this definition of veridicality. For counter examples, see Campbell (2008) and Fish (2013).

[2] The epistemological notion that the truth value of an event or statement rests on its correspondence with external reality (Norman, 1980).

[3] Pared-back selective realism is another position one could take; however, we hold that it is functionally akin to indirect realism given all such organisms would simplify their perceptions creating *Umwelten* that operate as species-specific (or any other taxonomic category) partial copies of their *Umgebung*.

logical limiting factors (e.g., Gottlieb, 2002; Gorea, 2011; Li et al., 2023), meaning object representations never fully capture their ontic referents. Interpretation, in addition to the filtering constraints of sense-perceptions, always mediates between the subjective representations and the Peircean object/referents. Insofar as what is perceived is not illusory, direct perception makes little to no reference to contingent hermeneutics because interpretation presents a divide where what is perceived need not correspond to external reality (Brown, 1992).[4] If what is perceived is contingent on the perceiving organism's sensory filters, how can the organism be confident its perceptions reflect aspects of reality rather than presenting mere fabrications?

Direct realists (e.g., Putnam, 1999; Searle, 2015; Beaton, 2016) argue that only what is dyadically perceived is real, because subjective representations must maintain structural uniformity (operationalized as an isomorph) with their referents (Boring, 1936). It is claimed such uniformity puts living organisms in a better position to act in the physical world. On this view, nonveridicality, and by extension indirect realism, is susceptible to illusory representations that are perceptually mistaken and evolutionarily deleterious (Hoffman et al., 2015; Hoffman, 2019; Prakash et al., 2020a, b). The illusory argument maintains that perceptions which do not dyadically match the external world may be false, leading to faulty, misleading associations (Brown, 1992). Faulty associations sow discord between behavior and environment. However, if perceptual function discerns the intrinsic properties of objects in the physical world, then the illusory argument fails for two reasons. Firstly, there is no demand that an object manifests itself at first glance; secondly, physical objects regularly do not possess the intrinsic properties they appear to have (e.g., looking into a mirror or still lake) (Brown, 1992). As a result, veridicality is suspect on its own merits. Additionally, veridicality postulates the same undifferentiated object-representation relations as direct realism, a category error seemingly inherent in dyadic metalanguages because it confuses the sign vehicle, the particular medium a signifier takes, for the ontic object being represented. As it does not follow that perceptual contingency is necessarily deleterious, illusory rebuttals do not dissuade nonveridicality as a viable perceptual candidate. While we may accept veridicality's logical operation as $Fp \rightarrow p$, a perceiver/perceived relationship tells us little to nothing about the nature of the presupposed objects/referents, other than, perhaps, affirming their ontic status. Direct realism has inspired brilliant works of visual perception (e.g., Gibson, 1986), and speech perception (e.g., Fowler, 1986), among others; however, does it possess the explanatory power to account for perception broadly? Unlikely.

4 The interface theory of perception

Evolutionary and systems biologists routinely use computational models for, among other things, hypothesis testing (e.g., Banzhaf & Eckman, 1995; Brodland, 2015; Bartocci & Lió, 2016). Hoffman et al. (2015) do the same to test various perceptual strategies. Within Bayesian estimation, veridical perception depends on the assump-

---

[4] Of course, this applies principally to sense perception rather than imagination, insofar as the two can be regarded as wholly discrete.

tion that evolution has shaped perceptual systems to accurately estimate, based on sensory information, the true structure of the objective world (Yuille & Bülthoff, 1996). As such, examining perceptual structure requires modelling the probabilities of various perceptions, as well as how those probabilities vary within different world states (Hoffman et al., 2015). Using measurable spaces – probability spaces for which probability measures are not yet specified – the original description of the ITP assesses how different perceptual strategies fare under evolutionary game conditions (Hoffman et al., 2015). The exposition presents the possible perceptual experiences of an organism by a measurable space where X is a set of possible experiences and *X* a collection of subsets of X called events [X; *X*] (Hoffman et al., 2015). This renders the world representable by a measurable space where W is a set of world states and *W* is again a collection of subsets called events [W; *W*] (Hoffman et al., 2015). Therefore, it is determined that a perceptual strategy (P) occurs if each state $w \epsilon W$ causes at most one perceptual experience $x \epsilon X$ in the absence of dispersion, such as noise (Hoffman et al., 2015). For example, the experience of different wavelengths of visible light allows one to easily differentiate bright red fruit from the green leafy background on a tree (in the absence of colorblindness).

Hoffman et al. (2015) list six[5] possible perceptual strategies that an organism may rely on to enable meaningful action in the objective world; (1) dispersion free, perceptions associated with singular experiences; (2) omniscient realism, which is the position that we see the world objectively and in totality for what it truly is; (3) naïve realism, which is synonymous with direct realism; (4) critical realism, which holds that some perceived properties of the world such as color and taste are not part of the objective world; (5) hybrid realism, which is an extension of critical realism but holding that some perceived properties such as shapes and motions are objectively true; and (6) their proposed nonveridical interface (Hoffman et al., 2015). All but the last are veridical and dyadic in structure. In order, each strategy bares the following properties: (1) $P: W \rightarrow X$, $X = W$ and P (isomorphic), (2) $X \subset W$ and P (also isomorphic), (3) X need not be a subset of W but P is nevertheless a homomorphism that preserves all structures on W, (4) $X \subset X$ satisfies $X \subset W$ and requires that P is isomorphic (e.g., some perceptions like shape are veridical, while others like color are nonveridical), and (5) $P: W \rightarrow X$ (without additional constraint and that the probabilities of perceptions are systematically related to probabilities of events in W) (Hoffman et al., 2015). The paper then ventures to observe the survival rates of each strategy relative to all the others using evolutionary game models. Evolutionary games simulate frequency-dependent selection where fitness strategies are not fixed but instead vary with the proportion of individuals in the population that employ each strategy (Parker, 1984; Hoffman et al., 2015). The underlying assumption is that survivability takes precedence insofar as individual organisms respond to selection pressures.

Assume an infinite population each with players pursuing a fixed strategy (who are in this case computer-generated models) randomly selected to interact in the games (Hoffman et al., 2015). Each player receives a payoff which is interpreted as reproductive success (fitness, functional saliency) leading to natural selection, which is

---

[5] Seven possible perceptual strategies are listed in the original paper. However, one is not assessed given the patterns found for the other six also hold in its case.

modeled by a replicator equation and randomized using Monte Carlo simulations. A replicator equation is a deterministic and non-innovative game dynamic (Hoffman et al., 2015). The results found that veridical strategies fared poorly against their nonveridical counterparts where 'fitness' (saliency) and 'truth' (one-to-one bijection) were distinguished (Hoffman et al., 2015). The paper then ponders whether organisms dependent on veridical perception would even remain long enough in the gene pool to propagate their 'preferred' perceptual structure. They use genetic algorithms which mimic biological evolution by solving both constrained and unconstrained optimization problems in sexually reproductive species (Hoffman et al., 2015). The algorithm involved a robot who efficiently gathers soda cans that were randomly distributed on a 10×10 grid of squares (Hoffman et al., 2015). The payoff function was set up such that the robot got 10 points for each can successfully picked up, lost one point each time it tried to pick up a can where there was none, and lost five points each time it tried to walk into a wall (Hoffman et al., 2015). The goal of the algorithm was to evolve a version of the robot that efficiently gathered the cans despite a lack of knowledge about the grid structure it was on.

After running many simulations with 200-odd competing robots and successive generations, the authors concluded that veridical strategies were regularly outcompeted by nonveridical strategies and competitive evolutionary dynamics (Hoffman et al., 2015). The paper further speculates that a veridical strategy with no selection pressures in its favor is very unlikely to appear in any generation to begin with, given a startling lack of fitness (Hoffman et al., 2015). To make sense of these results, the authors observe what they believe to be a latent anthropocentrism lingering in the work of many researchers interested in perception who regard human perception alone as veridical, but not that of 'simpler' organisms (Hoffman et al., 2015). Marr (1982), for example, argues that veridical perception is advantageous for human beings but would not be so for organisms such as insects and amphibians. To illustrate this hypothesis, Marr (1982) states that flies' visual systems serve the needs of their owners by providing very little objective information, unlike human visual systems. Assuming this is a fair characterization of Marr and others sharing similar viewpoints, it is implausible given every organism's biological constitution limits its possible range of sense perceptions, making such steadfast divisions between humans and other organisms untenable (Deely, 2001b; Hoffman et al., 2015; Hendlin, 2019a, b, 2020, among others). It is also unlikely that the perceptual systems of some organisms are a fallible heuristic, while those of others (namely *H. sapiens*) alone are an accurate guide.

5 Nonveridical but not illusory?

Having *prima facie* established via computer simulation that nonveridical perception is evolutionarily more competitive, ITP proposes an interface perceptual strategy to replace 'standard theories of perception' (Hoffman et al., 2015:1489). According to the ITP, perception occurs via an evolved, species-specific user interface that simplifies an organism's representations of environmental objects and their properties, entities that are necessarily more complex in their totality than as depicted by any given organism's senses (Hoffman et al., 2015). We retain focus on species-specificity because that is the taxonomic category most ecologically salient (Ulanowicz, 2001). Our human species, for example, cannot perceive ultraviolet light without the aid of technology (which is translated into interfaces which match our native perceptual capabilities). Our native inability to perceive is not because UV does not exist, but because we have not evolved the capacity or ordinary evolutionary need to detect certain wavelengths of light with our naked eyes. We live life somewhat blind to its existence, until someone gets sunburned. Similarly, dogs (*Canis familiaris*) cannot see the same range of visible light as humans and thus cannot experience the same colors that we can. This is not because those wavelengths of light do not exist, but rather because dogs have two cone receptors while humans possess three. Perception is not abstract and wholly cognitive, but embodied (Bridgeman and Tseng, 2011). The complexity of objects relative to their perceptual representations, which map one-to-one onto reality, would also be (potentially infinitely) costly to attempt to perceive in totality, leading organisms to expend energy remaining aware of inconsequential truths that do not contribute to fitness (Hoffman et al., 2015; Hoffman, 2016; Prakash et al., 2020b). Simplification, as it turns out, also has evolutionary advantages. Perceptual simplification through contingency is a survival mechanism. While not complete representations of external reality, perceptions are not necessarily illusory.

Take the example of a gun. A gun is a complex object that can be observed from many different levels of analysis. However, if one is pointed at you the threat of harm is real despite your simplified perceptions of this complex object. How locking mechanisms work, the physics of gunpower in a constrained chamber, etcetera, is ancillary to the practicality of acting in such a situation. Simplified perceptions and background cultural knowledge are enough to alert you to the gravity and actions the circumstances call for. Accordingly, you would be better served taking the threat seriously as an immediate relational event rather than processing the physical or chemical complexity of the object itself. Rather than being overwhelmed by fine-grained perception or expensive metabolic processes to understanding the sum-totality of sensory stimuli, nonveridical perception selects for *saliency*.

Indeed, all decision-making, for humans and other organisms rests on processes which shed all perceptual input nonessential to the immediate task at hand (which is not to say that such heuristics are immune to misfire, misselecting for saliency based on habit incorrectly for novel situations) (Rosenberg & McShea, 2007). Accordingly, the ITP proposes that the relationship between an organism's perceptions and reality is analogous to a desktop (space-time) and user icons (properties of objects within space-time) (Hoffman et al., 2015). A desktop or dashboard interface is by definition user friendly, facilitating meaningful interaction with icons which allow for simple navigation, but also mask the true structure of the computer's processing, the software which codes in 1's and 0's, let alone the underlying hardware made up of transistors, circuits, voltages, magnetic fields and firmware (Hoffman et al., 2015).

Hiding the true complexity of the computer *enables* meaningful action, such as writing a journal article or playing an online game, because interfaces simplify the world through functions that direct a user's effort away from *truths of no immedi-*

ate relevance to accomplishing valuable proximate goals (Hoffman et al., 2015).[6] Necessarily, access to the truth in its totality as concerns the state of external reality would be paralyzing (assuming such a feat could ever be perceptually possible or exhaustible). Partly, because such perception would be updating in real time over so vast information fronts, it would always be delayed in acting appropriate upon them. Such 'latency' challenges a best-of-both-worlds optimization with full fidelity to truth. Fidelity and latency become inversely proportional, when survival is based on not overthinking or -analyzing – where one has mere milliseconds to jump out of the way before a predator pounces. ITP thus diverges from traditional theories which insist that perceptions attune to elucidating the true situation in the objective universe, or that such knowledge would necessarily aid rather than possibly inhibit fitness. ITP instead posits that meaningful action is based on organisms' immediate needs to sustain them optimally through space and time without excess perceptual or computational demands (Hoffman et al., 2015; Hoffman, 2016). It weds perception to pragmatism. Once an organism capable of perception exists, its evolutionary trajectory and perceptions become inextricably linked in a process Heying and Weinstein (2021) call perception-mediated selection. Perception-mediated selection is a mode of natural selection recognizing perception's causal power in the evolutionary landscape.

At the same time, biosemiotics does not assign meaning-making (or significance) as reductive to fitness or reproduction. Meaning-making as the basis of semiosis provides many auxiliary, and from the perspective of sheer Darwinian evolutionary theory (specifically the modern synthesis), extravagant, sensations/experiences/foci/goals that afford organisms goal directedness that may sometimes not concord with fitness (e.g., Sebeok, 2001; De Loof, 2015; Noble, 2021). Regarding humanity, while self-regulating mechanisms for nonveridicality ordinarily do not allow (for long, anyhow) organisms to take as knowledge things that are not true[7] our capacity for symbolism has permitted us the 'unique method of mimicking the signs that trigger evolutionarily programmed instincts of [our] own species in order to manipulate them' (Hendlin, 2019a, b), producing unique challenges. Symbol manipulation takes pragmatism outside of sensory perception, instead placing intelligibility in abstraction, which places another layer of heuristics to deal with that have no physical object. If this is the case, the relevant question then becomes: what aspects of reality are organisms selecting for to best meet their needs, both on short-term and individual but also on intergenerational and holobiont-interspecies levels?

---

[6] One could say that in this way nonveridicality is a bit like Heidegger's hammer, which only is revealed qua separate object rather than tool when it stops working as one. The 1's and 0's of the computer only matter when they are not behaving as expected.

[7] See Berlinski (1988), for an interesting discussion that anticipates some of these issues.

6 Iconicity, indexicality, and symbolism

As established, both the ITP and biosemiotics: (1) assume nonveridicality, (2) are based upon a triadic relationship between a perceiver (interpretant), the indirectly perceived object, and directly perceived representation (representamen). To elaborate, an example from animal studies would be an animal (interpretant) perceiving via mental representations (representamen) something of nutritional value (object).[8] These behaviors occur because the animal constructs an experienced reality (*Umwelt*) that filters the objects and properties of the external environment (*Umgebung)* for saliency (what Tønnessen, 2018, following Uexküll, terms a *search image*). In other words, the organism's *Umwelt* is occupied by iconic representations (computer icon analogy in the ITP) which are functional approximations of its *Umgebung* (desktop as space-time analogy in the ITP). These 'icons' in biosemiotic language, represent the minimal units of meaning-making and simultaneously the beginnings of perception based on the primal experience of quality or *qualia* pre-association, analysis, or comparison (Favareau, 2015). Iconic representations occur from the first contact between an organism's perceptual interface and the objective world (Deely, 2001b). Peircean firstness, composed of primal sensations including shape, color, size, and texture among others correspond to the salient aspects of the things they represent (Hoffmeyer, 1993; Kockelman, 2005; Hoffman et al., 2015). Icons as fitness-tuned perceptual representations where awareness of, for example, different colors is evolutionarily advantageous build towards meaningful action through context whereby an organism learns to *associate* different primal sensations. This is the process of semiotic scaffolding (Favareau, 2015).

Where deterministic control mechanisms operate through an in-built anticipatory capacity, can be thought of as 'semiotic causation,' after Hoffmeyer (1993). For example, a large black (sink) hole in the ground is a falling-off place in which one should not step. Soft, white, cold fluff (snow) signifies that it is time to find warmth and shelter. These updated context-dependent relations produce indexical representations that are based on spatiotemporal and/or causal contiguity, arising when iconic representations assemble into categories that link quality and object manifestation (Hoffmeyer, 1993). Indexically grouping icons into agent-relevant categories (Peircean secondness) produces indexicalized icons which carve up external reality into discrete things and states, with indexes proper maintaining the particular relations that hold between those things and states (Kockelman, 2005; Favareau, 2015). Indexical representations constitute the beginning of an organism's 'understanding' of the world (Kockelman, 2005; Favareau, 2015). For example, primate gestural sequences are indexes given that the gestures point to something. Similarly, a fever is also an index given it points to an illness or virus that the body confronts (Kockelman, 2005). Indices can further be associated, leading to ideation (Peircean thirdness) where indexical representations scaffolded into symbolic relations (Favareau, 2015;

---

[8] Note that for biosemiotics, representations need not be mental (and certainly the field is not constrained to typical philosophy of mind-style representational constraints). Semiosis pushes against our notions of causation and mentation such that representing the world is understood as functional (as has been described), not veridical.

Parmentier, 2016). Symbols occurs when contextual linkages are themselves associated into conventions and or norms[9] (Deacon, 1997; Kockelman, 2005). Symbols abstractly stand-in for things they do not necessarily resemble (Deacon, 2011); therefore, iconic, indexical, and symbolic representations rely on modes of inference to be transformed into useful knowledge and/or information (Favareau, 2008).[10]

7 Abduction, induction, and deduction

The field of ecology relies on various information models to determine material and energy flows. These include eco-exergy models which assess the amount of work done within an ecosystem (e.g., Jørgensen & Nielsen, 2014), Fisher information which is a mathematic function of information retention inversely correlated with systems disorder (e.g., Equihua et al., 2020), and Shannon indexes which determine aspects of biodiversity including species abundance and coverage (Ulanowicz, 2001). These models accept syntactic elaborations of information, which while powerful, do not capture information's bivalent nature within cognitive and ecological systems (Abel & Stepp, 2003) as a state change where an organism's experiences and knowledge-base expand (Brier, 2008; Åsvoll, 2014; Maran & Kull, 2014). Hermeneutic approaches which emphasize the contextual/pragmatic dimensions of information explicate that 'in-formation' always exists for someone, rather than existing or doing work without an interpreter (Casagrande, 1999). Living organisms approach information not only as an independent property but as the process of becoming 'in-formed' about the objects and properties of their environments. For living organisms, information does not exist in a vacuum – it is always information for an interpreter or agent, made meaningful against a preexisting informational background. Kant made a similar distinction in his description of *phenomena* and *noumena* (Loughlin, 1987). To be 'in-formed', a constructive process, requires abduction, basal logical inference permitting an organism to draw conclusions about its environment from the simplest observations signaled by sense-data, including primal sensations (icons), context linkages (indices), and linkage abstractions (symbols). Abduction operates when an organism adopts 'hypotheses' that cannot be justified prior to interrogation (Abe, 2003; Barbieri, 2020), given this method of reasoning does not require a prior knowledge base to produce sign relations (Åsvoll, 2014).

For example, imagine a gang of meerkats (*Suricata suricatta*) in the wild. If one meerkat detects a rustling in the grass and observes other members of the group react-

---

[9] Kockelman (2005) prefers 'norms' to 'conventions' at this stage of semiosis as he reasons that norms require imitation and the ability to sanction non-normative behavior whereas conventions tend to be more rationalistic, taking the form of a social contract.

[10] There is an active debate in biosemiotics regarding the final or best schema for classifying Peirce's sign types, as they continually evolved and in some cases could be seen to imply contradictory elements over the course of his career. This is pertinent insofar as symbols are relegated to humans only, to humans plus 'animals like us', or whether forms of symbolic thinking in other forms, in their varieties as qualisigns, sinsigns, legisigns or dicisigns, are far more replete in experience throughout the organismal world. We do not maintain that complex sign use is the ambit of humans only. For an overview of some of these debates, see Stjernfelt (2014), Schilhab et al. (2012), and Peterson et al. (2018).

ing with alertness and moving away, the meerkat might abductively reason that there is a potential threat such as a predator nearby. In this case, the meerkat is making an inference based on observed behaviors and contextual cues, forming a hypothesis about the presence of danger. The meerkat uses its triadic perceptual interface to infer an appropriate behavioral response from socio-ecological cues. In other words, the meerkat as an interpretant perceives rustling grass (ecological feature of the meerkats' *Umgebung*) in conjunction with group alertness and precaution (social feature of the meerkats' *Umgebung*) as constituting a representamen/subjective representation which probabilistically signals that a predator (socio-ecological object/referent) is likely present. In this way, abduction is the first step in the simultaneous generation and expansion of perceptual knowledge which consists of semiotics necessary for 'in-formation' (Abe, 2003). The likely presence of the predator/referent diminishes both individual and group fitness. Within the meerkat's *Umwelt* these relations are quickly constructed, and survival is prioritized, relegating all other potential activities as less urgent until the threat is resolved. Green, rustling grass plus stationary gang (group of meerkats) as iconic representations link into the agent-relevant categories of probabilistic danger, calibrating the interpretant meerkat's behavioral responses to maximize fitness. The dynamics of kin selection then kick in.

Other pertinent forms of animal inference include induction and deduction (Abe, 2003). Once an organism's knowledge base is in-formed following the abductive process, inductive inferences search for tendencies among revealed sign relations, generating probabilistic rules, finding more examples, and add to background knowledge (Abe, 2003). Inductive knowledge can then be manipulated and updated through deductive inferences as well in the process of becoming 'in-formed'.[11] Regarding deduction, the most contentious of the three modes of reasoning, there remains academic debate as to whether nonhuman animals possess such capacities. Some affirm animal deduction, and others contest (Kravchenko, 2006; Duffrene et al., 2022). According to Peirce, these three methods of reasoning have no hierarchy, and abduction more specifically, is both the fundament and the zenith of reasoning because it is constantly integrating (like calculus) rather simply engaging in a linear or progressive mathematics (Short, 2007). In other words, abduction is recursive and multivalent, as it includes multiple levels of semiosis simultaneously rather than just solving for a single, isolated aim or equation. All of this suggests that information is a facet of something that can be picked up by an interpretant via specific representations which favor or privilege those aspects in favor of others. This process goes wrong when, via faulty inference, we create patterns from selected information which reinforce our own errors or biases (Hoffmeyer & Stjernfelt, 2016).

---

[11] Some literature argues that deduction requires reasoning to draw logical conclusions, a faculty usually correlated with higher cognitive function and the ability to think abstractly. By contrast, abduction and induction do not. For further discussion on the connection between abduction and generalization see Rivera and Becker (2007). For a discussion on abduction as incomplete parameter estimation see Kamiura (2011). For a critique of some of these ideas see Rivera (2008).

8 Why are some inferences incorrect?

Abduction, induction, and deduction facilitate 'hypothesis testing' because knowledge, whether cultural or not, becomes false or deleterious when type one and type two errors occur. Hypothesis errors corrupt an organism's knowledge base when: (1) a true null hypothesis is rejected or, (2) one fails to reject a false null hypothesis (Bernard, 2017). An example of a type one error: imagine a group of honeybees (i.e., *Apis cerana*) is foraging for nectar. One of the bees, while performing the waggle dance, which is a communication signal used to convey information about the location of food sources (Biesmeijer & Seeley, 2005), accidentally performs the dance with incorrect information due to a navigational error or confusion (perhaps due to pesticide poisoning). The other bees in the hive interpret this as indicating a rich nectar source in a particular direction and distance from the hive, resulting in a type one error and a significant portion of the foraging workforce following the misleading information provided by the bee's dance and flying in search of the nonexistent food source. Alternatively, an example of a type two error: imagine a scenario where a chimpanzee (*Pan troglodytes*) displays a submissive gesture towards another chimpanzee, such as crouching and presenting its back. This submissive behavior is typically a signal intended to appease or avoid conflict with the other individual (Roberts & Roberts, 2015). If the recipient chimpanzee misinterprets the submissive gesture as a sign of weakness or vulnerability rather than a gesture of submission, a type two error has occurred.[12] The indexical representations which compose the recipient primate's knowledge base do not concord with the socio-ecological cues/referents, leading to inaccurate inferences.

Symbols differ slightly because of their abstract nature. In sociocultural anthropology, E.B. Tyler (1867) coined the term *vestiges* to describe cultural practices that may have once possessed functionality which since has ceased, as the society changed over time. Culture is a repository of symbolic relations forming a knowledge base (Khumalo, 2023; Parmentier, 2016); as such, we reason that symbolic representations become vestiges and obsolete when the environment, whether political, social, or ecological detaches from the knowledge base. Detachment occurs once a symbol is no longer tethered to the indexes it presupposes, or philosophically when the objects and properties of external reality (ontology, *Umgebung*) no longer concord with their description (epistemology, *Umwelt*) as in-formation modalities (icons, indices, symbols) become incongruent. Vestiges are faulty symbolic inferences that no longer correspond with reality. These nonveridical semiotic relations depend on a corresponding relationship between what is, and representations of what is. Symbols become vestiges when they lose their sociological and biological value, becoming less salient due to emergent epistemic/ontic mismatches. As abstract modalities (Kockelman, 2005), symbols do not necessarily resemble the contextual linkages from which they derive; however, this only means that the *form* a symbol takes is flexible, rather than the sign relations undergirding it. A green traffic light signifies 'continue driving' in most of the world due to international law; however, in Japan

---

[12] There is growing literature critical of null-hypothesis significance testing as a means of generating accurate knowledge. See Harlow et al. (2016).

the bluest shade of green (which often just looks blue) is used. We can see that this color convention is arbitrary because it varies between contexts, but beyond that any other color could have been chosen to convey these messages such as purple, white, or pink. However, this normative/conventional reality while flexible in form is tethered to the underlying indexical scaffolds where the accepted symbol denotes the underlying reality that when driving a car one should heed those walking or driving in public, as well as the shared rules encouraging safe and (theoretically) efficient traffic flow. The congruency existing between the light color as a symbol, and the underlying social reality it signals is arbitrary, but importantly, shared.

Of course, not all signaling errors are grave. If one misreads traffic light signals there is a high probability of injury or death; however, many signaling errors are more benign. Pareidolia, the psychological phenomenon where mammal brains perceive familiar patterns, shapes, or meaning from nebulous stimuli (Zhou & Meng, 2020) like seeing faces in clouds is a generally harmless mismatch between a perceptual representation and the external reality. Seeing faces in clouds, on its own, is unlikely to lead to injury or death. Critics of the Interface Theory of Perception (ITP) (e.g., Charan et al., 2021) have argued that in situations of dramatic environmental change, interface perceiving organisms rapidly become uncompetitive. When heuristics become fixed and routinized, then they are less flexible to revision and change when major aspects of reality suddenly are altered.

Our evolutionary psychology and physiology may be nonveridical, but this might mean in very quickly changing environments that veridicality will be more adaptive. In these limit cases of disturbed *Umwelten* in which habits veer increasingly further from saliently mapping onto the *Umgebung*, more direct forms of realism would be more advantageous, despite Hoffman's (i.e., 2016) challenges. We agree with the critique, but view such situations evince the disunity between ontology and epistemology perceptually. Some (currently anthropogenic) environmental or social changes are too rapid for an organism to update its interface when based on long-honed instinct rather than norms. There may also be issues with Hoffman et al's definitions of 'truth' and 'real' (Fields et al., 2021). A contingent representation is not necessarily unreal, but may simplify reality too much. Representations must still concord with aspects of the referents they represent; just not in totality. For most cases, such representations are true *enough*, a hallmark of pragmatism. We accept, however, that both considerations exist metaphysically, contending only that knowledge and experiences are relative (while still being tethered to reality) in what Fields et al. (2021) call 'minimal physicalism'. Simultaneously, we are unwilling to say that we are physicalists, a topic for another paper, because following Goethe we believe perceptual representations result from relations between interpreting agents such as organisms and objects/referents in the physical universe (Vendler, 1995).[13] Lastly, while our synthesis may be read as postmodern given its appreciation for interpretation, relativity, and contingency (Hicks, 2019), we are diametrically opposed to thick constructivism given we maintain realism (the existence of truth statements and metanarratives) and, in principle, our ideas should produce testable hypotheses.

---

[13] This can be read as a criticism of Newtonian metaphysics for cognition and ecology. See Ulanowicz (2009).

9 Conclusions

If veridicality is indeed an unsuccessful evolutionary strategy in comparison to its nonveridical counterpart in most cases, corresponding notions of truth as a dyadic relationship are supported neither by ITP nor biosemiotics. Direct realism poses genuine concerns about the implications for knowledge production. Nonetheless, direct realism provides an unsatisfactory account of perception, and by extension, knowledge production, and human and nonhuman animal behavior. Because of its isomorphism, direct realism assumes that veridicality is preferable for survivability. However, the ITP not only brings that assumption into question, but also organisms' inherit sense-perceptions from their biological lineage that introduce interpretation (and consequently triadic meaning-making) into perception. Because of the limits of any one species to exhaustively one-to-one sense the world in its totality (or even the total facets or qualities of a given object), perception is better conceived according to a triadic relational model between perceiving organisms, perceived objects, and the subjectively perceived representation of the object (salient available features).[14] Dyadic perceptual structures attuned to truth – here defined as complex and undifferentiated by value functions – appear game-theoretically weaker compared to triadic perceptual strategies tuned to fitness, defined as truth simplified according to saliency (survivability). This is pragmatically argued according to the limited bandwidth, computational power, attentional awareness, and/or the necessity to reduce reality rather than exhaust all aspects of a situation and or thing. To decide means to cut ambiguities and choose from an array of options. Human and nonhuman animals alike interact with the physical world through evolved, species-specific perceptual interfaces that simplify the complexity of external reality allowing for effective and decisive action (Kull et al., 2011). Whatever reality is, it must be more complex than any organism's sense perceptions reveal, since every species apprehends a different *Umwelt* that partially but never fully overlaps with other species. Therefore, simplified mental representations of physical objects, or 'icons,' filter the external world so that it is not paralyzing. Icons scaffold together for all animal life into indexes, the associations between icons. Elaborated in human beings (especially but not exclusively) is the scaffolding of indexes into symbols, the abstract association between an 'image' and external object. This is the basis of culture (Cobley, 2016), which appears to be present in one form or another amongst different animals (Whiten, 2021). Given finite knowledge and the bodily correlates of mind to make sense of the world, human and nonhuman life engage in abduction, seeking knowledge discovery, seeking patterns, and generating hypotheses. This helps human and nonhuman animals accrue pertinent knowledge from properties and qualities of the physical world to weed out delirious or destructive 'beliefs.' This tending, however, does not suggest veridicality, but instead a logic of perceptual sufficiency (Princen, 2005), and suggests there are serious trade-offs between the ability to act and the ability to know (Stepp, 1999).

---

[14] Note: subjective here does not mean relativistic. Subjective representations must pass the intersubjectivity test amongst others or such subjective knowledge turns out to not be ultimately useful. See Appiah (2006).

Author contributions BK contributed to conceptualization, data collection, analysis, led the writing and contributed to review and editing. YHH contributed to conceptualization, analysis, review and editing, supervision, and writing.

Funding Not applicable.

Data availability Data sharing not applicable as no datasets generated and/or analyzed for this study.

Declarations

Ethical approval Not applicable.

Informed consent Not applicable.

Competing interests The Authors declare no competing interests, financial or otherwise.

Statement regarding research involving human participants and/or animals Not applicable.

References

Abe, A. (2003). Abduction and analogy in chance discovery. In Y. Ohsawa, & P. McBurney (Eds.), *Chance discovery (Advanced Information Processing)* (3rd ed., pp. 231–248). Springer Berlin. https://doi.org/10.1007/978-3-662-06230-2_16

Abel, T., & Stepp, J. R. (2003). A new ecosystems ecology for anthropology. *Conservation Ecology*, *7*(3), 1–13. https://www.jstor.org/stable/26271963

Appiah, K. A. (2006). The politics of identity. *Daedalus*, *135*(4), 15–22. https://doi.org/10.1162/daed.2006.135.4.15

Åsvoll, H. (2014). Abduction, deduction and induction: Can these concepts be used for an understanding of methodological processes in interpretative case studies? *International Journal of Qualitative Studies in Education*, *27*(3), 289–307. https://doi.org/10.1080/09518398.2012.759296

Banzhaf, W., & Eckman, F. H. (1995). *Evolution and biocomputation: Computational models of evolution*. Springer Science & Business Media. https://doi.org/10.1007/3-540-59046-3

Barbieri, M. (2020). The semantic theory of language. *Biosystems*, *190*, 104100. https://doi.org/10.1016/j.biosystems.2020.104100

Bartocci, E., & Lió, P. (2016). Computational modeling, formal analysis, and tools for systems biology. *PLoS Computational Biology*, *12*(1), e1004591. https://doi.org/10.1371/journal.pcbi.1004591

Beaton, M. (2016). Sensorimotor direct realism: How we enact our world. *Constructivist Foundations*, *11*(2), 265–276. http://constructivist.info/11/2/265

Berlinski, D. (1988). *Black mischief: Language, life, logic, luck*. Marina Books.

Bernard, H. R. (2017). *Research methods in anthropology: Qualitative and quantitative approaches*. Rowman & Littlefield.

Biesmeijer, J. C., & Seeley, T. D. (2005). The use of waggle dance information by honey bees throughout their foraging careers. *Behavioral Ecology and Sociobiology*, *59*, 133–142. https://doi.org/10.1007/s00265-005-0019-6

Boring, E. G. (1936). Psychophysiological systems and isomorphic relations. *Psychological Review*, *43*(6), 565–585. https://doi.org/10.1037/h0059300

Brier, S. (2008). *Cybersemiotics: Why information is not enough!* University of Toronto. https://doi.org/10.3138/9781442687813

Brodland, G. W. (2015). How computational models can help unlock biological systems. *Seminars in Cell & Developmental Biology*, *47–48*, 62–73. https://doi.org/10.1016/j.semcdb.2015.07.001

Brown, H. I. (1992). Direct realism, indirect realism, and epistemology. *Philosophy and Phenomenological Research*, *52*(2), 341–363. https://doi.org/10.2307/2107939

Campbell, J. (2008). Sensorimotor knowledge and naïve realism. *Philosophy and Phenomenological Research, 76*(3), 666–673. https://www.jstor.org/stable/40041203

Casagrande, D. (1999). Information as verb: Re-conceptualizing information for cognitive and ecological models. *Georgia Journal of Ecological Anthropology*, *3*(1), 4–12. https://doi.org/10.5038/2162-4593.3.1.1

Charan, A. R., Gharibzadeh, S., & Firouzabadi, S. M. (2021). Realism is almost true: A critique of the interface theory of perception. *ArXiv (Preprint)*, 1–18. https://doi.org/10.48550/arXiv.2111.03864

Cobley, P. (2016). *Cultural implications of biosemiotics* Springer Netherlands. https://doi.org/10.1007/978-94-024-0858-4

Deacon, T. W. (1997). *The symbolic species: The co-evolution of language and the brain*. W. W. Norton & Company.

Deacon, T. W. (2011). Beyond the symbolic species. In T. Schilab, F. Stjernfelt, & T. W. Deacon (Eds.), *The symbolic species evolved* (1st ed., pp. 9–38). Springer Netherlands. https://doi.org/10.1007/978-94-007-2336-8_2

Deely, J. (2001a). Physiosemiosis in the semiotic spiral: A play of musement. *Σημειωτκή-Sign Systems Studies*, *29*(1), 27–48. https://doi.org/10.12697/sss.2001.29.1.03

Deely, J. (2001b). *Umwelt Semiotica*, 1(4), 125–134.

De Loof, A. (2015). Organic and cultural evolution can be seamlessly integrated using the principles of communication and problem-solving: The foundations for an extended evolutionary synthesis (EES) as outlined in the mega-evolution concept. *Life: The Excitement of Biology*, *2*(4), 247–269. https://doi.org/10.9784/LEB2(4)DeLoof.01

de Saussure, F. (2004). Course in general linguistics. In J. Rivkin, & M. Ryan. *Literary theory: An anthology*, (2nd ed, pp. 59–71). Blackwell Publishing.

Duffrene, J., Petit, O., Thierry, B., Nowak, R., & Dufour, V. (2022). Both sheep and goats can solve inferential by exclusion tasks. *Animal Cognition*, *25*(6), 1631–1644. https://doi.org/10.1007/s10071-022-01656-y

Equihua, M., Aldama, M. E., Gershenson, C., López-Corona, O., Munguía, M., Pérez-Maqueo, O., & Ramírez-Carrillo, E. (2020). Ecosystem antifragility: Beyond integrity and resilience. *PeerJ*, *8*, 8533. https://doi.org/10.7717/peerj.8533

Favareau, D. (2008). Collapsing the wave function of meaning: The epistemological matrix of talk-in-interaction. In J. Hoffmeyer (Ed.), *A legacy for living systems* (1st ed., pp. 169–211). Springer Netherlands.

Favareau, D. (2015). Symbols are grounded not in things, but in scaffolded relations and their semiotic constraints (or how the referential generality of symbol scaffolding grows minds). *Biosemiotics*, *8*(2), 235–255. https://doi.org/10.1007/s12304-015-9234-3

Fields, C., Glazebrook, J. F., & Levin, M. (2021). Minimal physicalism as a scale-free substrate for cognition and consciousness. *Neuroscience of Consciousness, 2021*(2), 1–15. https://doi.org/10.1093/nc/niab013

Figueredo, A. J., Vásquez, G., Brumbach, B. H., Schneider, S. M., Sefcek, J. A., Tal, I. R., Hill, D., Wenner, C. J., & Jacobs, W. J. (2006). Consilience and life history theory: From genes to brain to reproductive strategy. *Developmental Review*, *26*(2), 243–275. https://doi.org/10.1016/j.dr.2006.02.002

Fish, W. (2013). Perception, hallucination, and illusion: Reply to my critics. *Philosophical Studies, 163*(1), 57–66. https://doi.org/10.1007/s11098-012-0072-8

Fowler, C. A. (1986). An event approach to the study of speech perception from a direct–realist perspective. *Journal of Phonetics*, *14*(1), 3–28. https://doi.org/10.1016/s0095-4470(19)30607-2

Giannakidou, A. (1998). *Polarity sensitivity as (non)veridical dependency*. John Benjamins. https://doi.org/10.1075/la.23

Gibson, J. J. (1986). *The ecological approach to visual perception*. Lawrence Erlbaum. https://doi.org/10.4324/9780203767764

Gorea, A. (2011). Ticks per thought or thoughts per tick? A selective review of time perception with hints on future research. *Journal of Physiology-Paris*, *105*(4–6), 153–163. https://doi.org/10.1016/j.jphysparis.2011.09.008

Gottlieb, G. (2002). On the epigenetic evolution of species-specific perception: The developmental manifold concept. *Cognitive Development*, *17*(3–4), 1287–1300. https://doi.org/10.1016/s0885-2014(02)00120-x

Harlow, L. L., Mulaik, S. A., & Steiger, J. H. (2016). *What if there were no significance tests?* Routledge. https://doi.org/10.4324/9781315629049

Hendlin, Y. H. (2019a). I am a fake loop: The effects of advertising-based artificial selection. *Biosemiotics, 12*(1),131–156. https://doi.org/10.1007/s12304-018-9341-z

Hendlin, Y. H. (2019b). Methodologies of curiosity: Epistemology practice and the question of animal minds. *Biosemiotics, 12*(2), 349–356. https://doi.org/10.1007/s12304-019-09357-9

Hendlin, Y. H. (2020). The human turn in biosemiotics. In L. Lacková, C. J. Rodríguez, & K. Kull (Eds.), *Gatherings in Biosemiotics XX.* University of Tartu Press.

Heying, H., & Weinstein, B. (2021). *A hunter-gatherer's guide to the 21st century: Evolution and the challenges of modern life*. Penguin.

Hicks, S. R. C. (2019). *Explaining postmodernism: skepticism and socialism from Rousseau to Foucault*. Connor Court Publishing.

Hoffman, D. D. (2016). The interface theory of perception. *Current Directions in Psychological Science*, *25*(3), 157–161. https://doi.org/10.1177/0963721416639702

Hoffman, D. D. (2019). Do we see reality? *New Scientist*, *243*(3241), 34–37. https://doi.org/10.1016/s0262-4079(19)31434-4

Hoffman, D. D., Singh, M., & Prakash, C. (2015). Probing the interface theory of perception: Reply to commentaries. *Psychonomic Bulletin & Review*, *22*(6), 1551–1576. https://doi.org/10.3758/s13423-015-0931-3

Hoffmeyer, J. (1993). *Signs of meaning in the universe*. Indiana University Press.

Hoffmeyer, J., & Stjernfelt, F. (2016). The great chain of semiosis: Investigating the steps in the evolution of semiotic competence. *Biosemiotics*, *9*(1), 7–29. https://doi.org/10.1007/s12304-015-9247-y

Jørgensen, S. E., & Nielsen, S. N. (2014). Use of eco-exergy in ecological networks. *Ecological Modelling*, *293*, 202–209. https://doi.org/10.1016/j.ecolmodel.2014.05.007

Kamiura, M. (2011). Abduction as incomplete parameter estimation. tripleC: Communication, capitalism & critique. *Open Access Journal for a Global Sustainable Information Society*, *9*(2), 494–501. https://doi.org/10.31269/triplec.v9i2.303

Khumalo, B. (2023). The environment as a semiotic information matrix for human ecology. In A. Biglari (Ed). *Open semiotics volume 4* (pp. 363–374). Éditions L'Harmattan.

Kockelman, P. (2005). *The semiotic stance semiotica*, *157*(1), 233–304. https://doi.org/10.1515/semi.2005.2005.157.1-4.233

Kravchenko, A. (2006). Cognitive linguistics, biology of cognition and biosemiotics: Bridging the gaps. *Language Sciences, 28*(1), 51–75. https://doi.org/10.1016/j.langsci.2005.02.002

Kull, K., Emmeche, C., & Hoffmeyer, J. (2011). Why biosemiotics? An introduction to our view on the biology of life itself. In C. Emmeche, & K. Kull (Eds.), *Towards a semiotic biology: Life is the action of signs* (1st ed., pp. 1–21). World Scientific. https://doi.org/10.1142/9781848166882_0001

Li, B., Solanas, M. P., Marrazzo, G., Raman, R., Taubert, N., Giese, M., & de Gelder, B. (2023). A large-scale brain network of species-specific dynamic human body perception. *Progress in Neurobiology*, *221*(102398), 1–12. https://doi.org/10.1016/j.pneurobio.2022.102398

Loughlin, G. (1987). Noumenon and phenomena. *Religious Studies*, *23*(4), 493–508. https://doi.org/10.1017/s0034412500019077

Maran, T., & Kull, K. (2014). Ecosemiotics: Main principles and current developments. *Human Geography*, *96*(1), 41–50. https://doi.org/10.1111/geob.12035

Marr, D. (1982). *Vision* Freeman. https://doi.org/10.7551/mitpress/9780262514620.001.0001

Noble, D. (2021). The illusions of the modern synthesis. *Biosemiotics*, *14*(1), 5–24. https://doi.org/10.1007/s12304-021-09405-3

Norman, J. (1980). Direct and indirect perception of size. *Perception & Psychophysics*, *28*(4), 306–314. https://doi.org/10.3758/bf03204389

Palmer, S. E. (1999). *Vision science: Photons to phenomenology*. MIT Press.

Parker, G. A. (1984). Sperm competition and the evolution of animal mating strategies. In R. L. Smith (Ed). *Sperm competition and the evolution of animal mating systems* (pp. 1–60). Elsevier. https://doi.org/10.1016/B978-0-12-652570-0.50008-7

Parmentier, R. J. (2016). *Signs and society: Further studies in semiotic anthropology*. Indiana University Press. https://doi.org/10.2307/j.ctt2005sns

Peterson, J. V., Thornburg, A. M., Kissel, M., Ball, C., & Fuentes, A. (2018). Semiotic mechanisms underlying niche construction. *Biosemiotics*, *11*(2), 181–198. https://doi.org/10.1007/s12304-018-9323-1

Piaget, J. (1979). Relations between psychology and other sciences. *Annual Review of Psychology*, *30*(1), 1–9. https://doi.org/10.1146/annurev.ps.30.020179.000245

Pizlo, Z., Li, Y., Sawada, T., & Steinman, R. M. (2014). *Making a machine that sees like us*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199922543.001.0001

Prakash, C., Fields, C., Hoffman, D. D., Prentner, R., & Singh, M. (2020b). Fact, fiction, and fitness. *Entropy*, *22*(5), 1–23. https://doi.org/10.3390/e22050514

Prakash, C., Stephens, K. D., Hoffman, D. D., Singh, M., & Fields, C. (2020a). Fitness beats truth in the evolution of perception. *Acta Biotheoretica*, *69*(3), 319–341. https://doi.org/10.1007/s10441-020-09400-0

Princen, T. (2005). *The logic of sufficiency*. MIT Press.

Putnam, H. (1999). *The threefold cord: Mind, body, and world*. Columbia University.

Rivera, F. D. (2008). On the pitfalls of abduction: Compolicities and complexities in patterning activity. *For the Learning of Mathematics*, *28*(1), 17–25. http://www.jstor.org/stable/40248593

Rivera, F. D., & Becker, J. R. (2007). Abduction in pattern generalization. *Proceedings of the 31st Conference of the International Group for the Psychology of Mathematics Education*. Seoul: PME (pp. 97–104).

Roberts, A. I., & Roberts, S. G. B. (2015). Gestural communication and mating tactics in wild chimpanzees. *PloS One*, *10*(11), 1–20. https://doi.org/10.1371/journal.pone.0139683

Rosenberg, A., & McShea, D. W. (2007). *Philosophy of biology: A contemporary introduction*. Routledge. https://doi.org/10.4324/9780203926994

Rupnow, R. (2021). Conceptual metaphors for isomorphism and homomorphism: Instructors' descriptions for themselves and when teaching. *The Journal of Mathematical Behavior*, *62*(100867), 1–14. https://doi.org/10.1016/j.jmathb.2021.100867

Schilhab, T., Stjernfelt, F., & Deacon, T. W. (2012). *The symbolic species evolved*. Springer Netherlands. https://doi.org/10.1007/978-94-007-2336-8

Searle, J. (2015). *Seeing things as they are: A theory of perception*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199385157.001.0001

Sebeok, T. A. (1980). *How animals communicate*. Indiana University Press.

Sebeok, T. A. (2001). *Signs: An introduction to semiotics*. University of Toronto.

Sharov, A. A. (1992). Biosemiotics: A functional-evolutionary approach to the analysis of the sense of information. In T. A. Sebeok, & J. Umiker-Sebeok (Eds.), *The semiotic web 1991: Biosemiotics* (1st ed., pp. 345–373). De Gruyter.

Sharov, A. A. (2010). Functional information: Towards synthesis of biosemiotics and cybernetics. *Entropy, 12*(5), 1050–1070. https://doi.org/10.3390/e12051050

Short, T. L. (2007). *Peirce's theory of signs*. Cambridge University Press. https://doi.org/10.1017/CBO9780511498350

Stepp, J. R. (1999). Prospectus for information ecology. *Georgia Journal of Ecological Anthropology*, *3*(1), 38–74. https://doi.org/10.5038/2162-4593.3.1.4

Stjernfelt, F. (2014). *Natural propositions: The actuality of Peirce's doctrine of Dicisigns*. Docent.

Tønnessen, M. (2018). The search image as link between sensation, perception and action. *Biosystems*, *164*, 138–146. https://doi.org/10.1016/j.biosystems.2017.10.016

Tseng, P., & Bridgeman, B. (2011). Improved change detection with nearby hands. *Experimental Brain Research*, *209*(2), 257–269. https://doi.org/10.1007/s00221-011-2544-z

Tylor, E. B. (1867). Phenomena of the higher civilisation: Traceable to a rudimental origin among savage tribes. *Anthropological Review*, *5*(18/19), 303–314. https://doi.org/10.2307/3024922

Ulanowicz, R. E. (2001). Information theory in ecology. *Computers & Chemistry*, *25*(4), 393–399. https://doi.org/10.1016/s0097-8485(01)00073-0

Ulanowicz, R. E. (2009). *A third window: Natural life beyond Newton and Darwin*. Templeton Foundation.

Vendler, Z. (1995). Goethe, Wittgenstein, and the essence of color. *The Monist*, *78*(4), 391–410. https://doi.org/10.5840/monist199578428

von Uexküll, J. (1926). *Theoretical Biology*. Harcourt, Brace & Co.

Whiten, A. (2021). The burgeoning reach of animal culture We are not alone. *Science, 372*(6537), eabe6514. https://doi.org/10.1126/science.abe6514

Wilson, M. (2001). Perceiving imitatible stimuli: Consequences of isomorphism between input and output. *Psychological Bulletin*, *127*(4), 543. https://doi.org/10.1037/0033-2909.127.4.543

Yuille, A. L., & Bülthoff, H. H. (1996). Bayesian decision theory and psycho- physics. In D. Knill, & W. Richards (Eds.), *Perception as Bayesian inference* (1st ed., pp. 123–162). Cambridge University Press.

Zhou, L. F., & Meng, M. (2020). Do you see the face? Individual differences in face pareidolia. *Journal of Pacific Rim Psychology*, *14*(2), 1–8. https://doi.org/10.1017/prp.2019.27

Authors and Affiliations

Brian Khumalo[1] · **Yogi Hale Hendlin**[2,3]

✉ Yogi Hale Hendlin
hendlin@esphil.eur.nl

Brian Khumalo
b.khumalo@ufl.edu

[1] Department of Anthropology, University of Florida, Gainesville, FL, USA

[2] Erasmus School of Philosophy, Core Faculty, Dynamics of Inclusive Prosperity Initiative, Erasmus University, Burgemeester Oudlaan 50 Bayle Building, Rotterdam 3000 DR, The Netherlands

[3] Environmental Health Initiative, University of California, San Francisco, USA