A Biosemiotics Perspective on Dogs' Interaction with Interfaces: an Analytical and Design Framework

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ABSTRACT - Understanding how animals might make sense of the interfaces they interact with is important to inform the design of animal-centered interactions. In this regard, *biosemiotics* provides a useful lens through which to examine animals' interactions with interfaces and the sensemaking mechanisms that might underpin such interactions. This paper leverages Uexküll's *Umwelt theory*, Peirce's *logic of sign relations* and Gibson's *theory of affordances* to analyze examples of dogs' interactions with interfaces, particularly the role of the semiotic mechanisms of *indexicality* and *isomorphism*. Based on these analyses, the paper derives design implications, and proposes a semiotic framework to support the analysis and design of canine-centered interactions. The framework could be subsequently extended to support the analysis and design of interactive systems for other species.

BIOGRAPHICAL NOTE - Clara Mancini is full professor of Animal-Computer Interaction in the School of Computing and Communications, at The Open University (OU), UK, and founding head of the OU's Animal-Computer Interaction (ACI) Laboratory. Her research focuses on the design of animal-centered interactive systems and on the investigation of multispecies sensemaking during interaction, as well as on the development of animal-centered research methods and ethics. Extensively published in leading interaction design, animal-computer interaction and animal behavior conferences and journals, her research aims to develop ACI as a discipline as well as contribute towards multispecies wellbeing and inclusion, interspecies coexistence and cooperation.

1 INTRODUCTION

Understanding how animals might make sense of the interfaces they interact with is important to inform the design of animal-centered systems. This is a fundamental ambition of researchers who work within the field of Animal-Computer Interaction (ACI) (Mancini et al. 2017), paralleling the human-centered perspective that characterized the development of Human-Computer Interaction. In particular, the cognitive framework of User-Centered Design (UCD) (Norman and Draper 1986) has informed conceptualizations of canine-centered design, including for example Resner (2001)'s and Freil et al. (2017)'s design frameworks, or Zeagler et al. (2014)'s and Ruge et al. (2019)'s evaluation frameworks. At the same time, canine-centered design has also been influenced by behaviorism (Skinner 1959), whereby the principles of associative learning have informed experimental protocols to study dogs' interactions with systems, as exemplified by Byrne et al. (2016) or Mancini and Lehtonen (2018), among others.

Although these approaches have provided important frames of reference for ACI research and design, they do not address the sensemaking mechanisms that may underpin interaction or associative learning, and that may inform the design of canine interfaces. This paper discusses how *biosemiotics*, the study of signification across the natural world, could help designers focus on animals' sensemaking mechanisms and how these might be leveraged when designing animal-centered interactive systems. To this end, the paper builds on Uexküll (1985)'s *Umwelt theory*, Peirce (1893-1910)'s *logic of sign relations* and Gibson (1977)'s *theory of affordances* to analyze examples of dogs' interactions with interfaces, and to then derive implications for interface design. The paper also proposes a framework to help designers analyze and design dogs' interactions with interfaces from a semiotic perspective. The framework could be subsequently extended to also support the analysis and design of animal-centered systems for other species.

2 INFLUENCE OF COGNITIVE AND BEHAVIORIST APPROACHES ON CANINE INTERACTION DESIGN

Norman (1986) describes the interaction of a user with a system as the bridging of a gap occupied by two gulfs. The user crosses the *gulf of execution* by forming the intention to complete a task, by deciding the required action sequence based on their perception of the interface's affordances (i.e. the elements of an interface indicating how to interact with it and enabling fruitful interaction - Norman 1999), and by physically interacting with the system's input mechanisms. The user then crosses the *gulf of evaluation* by interpreting the system's status based on their perception of the interface's feedback (i.e. the confirmatory response produced by an interface upon interaction), and by evaluating their actions' outcome in relation to their original intention. The way in which a user perceives and understands an interface's affordances, and the related feedback they receive upon interacting with them, determines their understanding of how a system works. Thus, the concepts of *affordance* and *feedback* are central within UCD (Norman and Draper 1986), along with basic principles such as *perceivability* and *consistency*.

These concepts are also central within the work of researchers who have framed animals' interactions with systems from a UCD perspective, from Resner (2001)'s early framework for the design of a human-dog remote communication system for companion dogs to Freil et al. (2017)'s more recent framework for the design of canine-centered computing systems for working dogs. But, while this work highlights the importance of designing interfaces whose affordances capitalize on dogs' natural abilities of perception and interaction, and on forms of interaction that are already familiar to them, there has been little discussion as to how dogs' natural abilities might inform their interaction. Similarly, UCD-derived concepts such as usability goals (e.g. learnability, memorability) and user experience goals (e.g. enjoyability) have been applied to the evaluation of interfaces, whereby researchers have measured how quickly a dog might learn to interact with an interface, how many errors they might make (Zeagler et al. 2014, Ruge et al. 2019), how willingly they might engage and what demeanor they might exhibit (Byrne et al. 2016, Ruge et al. 2018). However, beyond being leveraged to broadly conceptualize dog's interaction with interfaces, UCD has provided little insight into how dogs might make sense of an interface's affordances and the topic has rarely been discussed (Mancini et al. 2016, Mancini et al. 2012).

As a result, although the affordances of canine interfaces have generally been designed taking into account dogs' sensory and physical characteristics, the selection of different designs has not explicitly been informed by canine sensemaking principles; rather, it has mostly been informed by existing practices (e.g. with devices which dogs were already trained to use or with which they were already familiar – Robinson et al. 2014) or by trial-and-error experimentation (e.g. with a range of ad-hoc devices which dogs were being trained to use – Freil et al. 2017). Thus, although dogs' ability to interact with different affordances is usually empirically evaluated, no approach has so far been available to inform the principled design of affordances and interfaces to best support dogs' sensemaking in the first place.

Aside from UCD, behaviorism has been another major influence on animal-computer interaction research, where classical and operant conditioning are often leveraged when training dogs to interact with systems, particularly where the aim is enabling them to perform specific tasks (Jackson et al. 2015, Robinson et al. 2015, Mancini and Lehtonen 2018). As mentioned above, classical and operant conditioning have also been widely applied for measuring the usability and user experience of canine interactive systems, and thus evaluating them (Zeagler et al. 2014, Byrne et al. 2016, Ruge et al. 2018, Ruge et al. 2019). However, like UCD, the behaviorist approach has not helped researchers envisage what might make a canine interface more or less understandable and, thus, more usable or enjoyable for dogs (such that they might even autonomously figure it out and spontaneously interact with it with no need for training).

Skinner (1959)'s famous operant conditioning chamber was itself an interactive system through which an experimenter could control the delivery of reinforcing or punishing stimuli in response to behaviors voluntarily performed by a subject, from which he derived *associative learning* rules. For example, these specify that consistent stimulus delivery in response to a behavior accelerates learning, that delays in response delivery weaken the learning effect, or that increases in reward or punishment levels increase the learning effect. However, as Motamedi Fraser (2019) argues, "*models of stimulus-response that define behaviorist theories of learning…have little to say about* how *those associations are forged in practice (other than that they are strengthened by spatio-temporal contiguity and can be manipulated by intervals and ratios of reinforcement)*" (p.382). Indeed, the question arises as to whether associative learning rules alone can account for canine sensemaking processes or whether other mechanisms might be involved; and as to what mechanisms might determine *how* associations are forged during interaction and how such mechanisms could be leveraged to inform the design of canine-centered interfaces that best support dogs' sensemaking.

3 A BIOSEMIOTICS PERSPECTIVE ON INTERACTION

Biosemiotics is the study of signification across the natural world and how, through signification, the subjective experience of organisms, which depends on their biological constitution, plays a causal role in the ongoing co-organization of nature (Favareau 2010, p.43). By understanding information as a functional relation of all life processes, from embryonic development (Barbieri 1998) to artistic expression, biosemiotics reconciles the cognitive and behaviorist perspectives (Favareau 2010) beyond the Cartesian mind-body dualism (Eder and Rembold 1992).

Pioneered by Sebeok (1979), who in the '60s merged the study of signs with the study of evolution founding zoosemiotics (Favareau 2010, p.35), biosemiotics fundamentally challenged the anthropocentric assumption that humans were the only sign-using species. In Hoffmeyer (1993)'s words, all organisms "*live, first and foremost, in a world of signification…everything an organism senses signifies something to it…*" (p.vii). The author calls this world *semiosphere* (Lotman 1990), arguing that it is only through the lens of the *semiosphere* that the biosphere can be understood. As Favareau explains, "*it is precisely the naturalistic establishment of sign relations that bridges the subject-dependent experience…with the inescapable subject-independent reality of alterity…that all organisms have to find some way to successfully perceive and act upon in order to maintain themselves in existence*" (Favareau 2010, p.6).

Two fundamental influences on Sebeok's development of biosemiotics were Uexküll (1985)'s *Umwelt* theory and Peirce's (1893-1910) logic of *sign relations*.

3.1 The world from the organism's perspective

Uexküll (1909)'s *Umwelt* theory counterpoints Darwin's theory of evolution as a purposeless process of natural selection fundamentally determined by chance. For Uexküll, individual organisms have purposeful capacities of perception and action, on the one hand, and biological drives, motivations and goals, on the other hand, which are determined by their biological constitution (Uexküll 1926) and which enable them to negotiate the complex environment in which they live and with which they are in a relation of dynamic interaction. Each animal has their unique model, their subjective interpretation of their surroundings - their *Umwelt*, which accounts for phenomena that are relevant to them and their survival. To survive and evolve, an animal needs to constantly negotiate their *perception* of the world and their *actions* upon the world; developing an *Umwelt* enables them to become part of the semiotic network of their ecosystem, to predict and respond to events that might be threatening or beneficial, and to negotiate social interactions (Hoffmeyer 1993). Within their ecological semiotic network, Abrantes (2005) notes, an animal recognizes internal and external signs that trigger their biological drives and motivate behaviors whose purpose is to fulfil drive-related goals. For one example, the goal of the *self-preservation* drive is to maintain metabolism and comfort, with relevant signs (e.g. the sight of prey) motivating self-preserving behavior (e.g. hunting behavior) (Abrantes, 2005).

Here, Barbieri (2008) distinguishes between *decoding*, when signs have only one possible meaning, and *interpreting*, when signs' meaning is context dependent. The author posits that the behavior of primitive organisms was entirely determined by the decoding of genetic signals. However, genetic predetermination limited organisms' capacity to respond adaptively to environmental variations. Eventually, more complex organisms that could remember the results of previous experiences became able to interpret environmental signs based on learnt context-dependent rules, thus increasing their behavioral repertoire, so they could respond more flexibly to complex environmental conditions. In more complex organisms, some signs still elicit a genetically predetermined response (e.g. a fast moving object eliciting chasing behavior), suggesting that they have a genetically determined meaning (Maynard Smith and Harper 2003), although this might adaptively change through learning (e.g. if, through repeated exposure, chasing the object turns out to be fruitless).

Although another's *Umwelt* may never be understood (Nagel 1974), for researchers who aim to design systems and interfaces that animals can make sense of and interact with effectively, considering the *semiotic processes* that might inform the animals' *Umwelt* (Hook 2019, Metcalfe 2015) can at least orient the design process. Peirce's logic of *sign relations* provides a model to examine such processes.

3.2 Signs as symbolic, iconic and indexical relations

In his logic of *sign relations*, Peirce (1893-1910) defines a sign as "*something which stands for something to someone in some respect or capacity*" (Favareau 2010, p.122). Hoffmeyer (1993, p.19) illustrates this with the example of a child who develops a rash, whose mother interprets it as a sign of illness and whose doctor interprets it as a sign of measles. Thus, a sign is a *triadic relation* among three elements: a *sign vehicle* (e.g. the rash); the *sign object* to which the sign vehicle refers (e.g. illness for the mother, measles for the doctor); and an *interpretant*, i.e. the system which establishes the relation between the vehicle and its object (e.g. the mother's mental process; the doctor's mental process). Thus, the sign interpreted by the mother is not the same sign interpreted by the doctor, even though the vehicle is the same. Peircean sign relations comprise symbols, icons and indexes (Favareau 2010, pp.125-133):

- **symbols** are conventional signs, whereby the relation between vehicle and object is abstract and arbitrary (e.g. words, mathematical formulae); they signify what they do only because they are understood to have that meaning, so any vehicle can be used as a symbol for any object by convention
- **icons** relate vehicle and object by similarity and divide into three categories: *images*, whereby vehicle and object share a likeness in some respect (e.g. a portrait resembling its subject); *diagrams*, whereby vehicle and object share some isomorphism, i.e. some analogous structural properties (e.g. a geographic map capturing the topography of a territory); *metaphors*, whereby vehicle and object are related by some characteristic parallelism (e.g. a blossoming flower representing the development of a child)
- **indexes** relate vehicle and object by contiguity or causality; an index points to a particular phenomenon such that vehicle and object have a concrete and 'necessary' (as opposed to abstract and arbitrary) relation (e.g. striations in rocks indicate a particular tectonic event); furthermore, an index joins two portions of an

experience, i.e. the experience of the vehicle and the experience of the object (e.g. a siren's sound and an ambulance's appearance are two portions of the same experience).

Kohn (2010) points out how indexicality is a universal semiotic process across the animal kingdom, also informing sensemaking within many human-animal interactions. For example, indexicality underpins the associative learning processes that are leveraged during dog training: in classical conditioning, a stimulus is associated with the delivery of another stimulus by space-temporal contiguity, so the former becomes a signal announcing the latter (e.g. a marker used to signal an impending reward); in operant conditioning, a stimulus is delivered following a behavior, as though it was its consequence (e.g. a food treat delivered as a reward); additionally, a stimulus might be delivered as the behavior is performed, until the former becomes a signal eliciting the latter (e.g. a cue used to request a behavior).

Indexical semiosis has been discussed in the context of human-dog interactions mediated by technology (Mancini et al. 2012). But what semiotic processes might inform dogs' sensemaking of and interaction with interfaces and their affordances? How might a semiotic analysis support the design of canine-centered interfaces?

4 THE SEMIOTICS OF AFFORDANCE

As mentioned above, the concept of affordance is central in interaction design, because the user's understanding of an interface's affordances will determine how they understand and interact with a system. The following sections examine this concept from a semiotic perspective.

4.1 Gibson's theory of affordances

In Gibson (1977)'s theory, an affordance is "*a specific combination of the properties"* (p. 67) of an object that is "*uniquely suited* [to an animal's] *nutritive system or...action system or…locomotor system*" (p.79). Thus, affordances are ecological properties expressing a relation between an animal and his environment; they imply possibilities for action that an animal with certain characteristics can take advantage of in his ecological *niche*.

Gibson defines affordances as "*invariant combinations of properties*" (p.68), bringing the example of a *sit-on-able* object, which features a rigid, level, flat and extended surface raised above the ground at the height of human knees. What affords sitting for a human are not the object's physical properties taken in isolation; rather, the combination of properties taken together make possible, and invite, the action of sitting. This invariant combination of properties constitutes a *common denominator* of the possible variations of a 'seat'. In Peircean terms, an affordance is an *index*, which signals the potential for a particular kind of interaction (e.g. sitting) for a particular interpretant (e.g. human); at the same time, the combination of properties that make-up the affordance is a *diagram* of any object that has that affordance (e.g. an archetypical chair) enabling the interpretant to recognize the same affordance they might have experienced in other objects (e.g. different kinds of chair).

For Gibson, "*the affordance may be more easily perceived by an animal than the properties in isolation, for the invariant combination of properties is meaningful whereas any single property is not*" (p.67-68). Affordances that are meaningful, because "*they specify benefits and dangers for the given observer*" (p.80), are more readily perceivable; while affordances whose relevance is not obvious to the observer may only be discovered through interaction. Affordances may also be misperceived, if the information the observer receives via their sensory channels is misleading. For example, someone may attempt to walk through a closed glass door only to discover that the perceived opening is *not walk-through-able*.

4.2 Affordance as a basis for *substitution*

Because objects may have multiple affordances (Gibson 1977), the question arises as to what might direct someone's perception towards one or another affordance of an object at any given time. In this regard, Gombrich (1963) examines the relation between a real horse and a hobby horse: being just a stick topped by a rudimentary horse-head effigy, the latter bears little resemblance to the former; but, for a child at play, it is an acceptable *substitute* on two counts: because it is ridable - i.e. both horses share "*a formal aspect which fulfil*[s] *the minimum requirement for the performance of the function*" (p.4) - and because riding *matters* to the child - i.e. wanting to ride enables the child to perceive the rideability of the hobby horse. Gombrich argues that substitutes fulfil *biological functions* and the stronger a *drive* to fulfil a function the fewer formal requirements an object needs to meet before it qualifies as an adequate substitute. For example, a cat runs after a ball as if it were a mouse because the ball's chase-ability fulfils the animal's strong chase drive (in Abrantes' terms, the motion of the ball is a sufficient sign to trigger such a strong drive and motivate the chasing behavior). Additionally, Gombrich points out how the same stick that in one context might represent a horse, in another context might represent a sword or something else. In brief, the effectiveness of a substitute depends on the *relevance* of the function it performs in a *particular context*, provided that the substitute shares with the object for which it substitutes *aspects that are essential to performing the function*.

In Peircean terms, Gombrich's hobby horse's affordance is a rudimentary *diagram* of a real horse; in the perception of the child (the interpretant), its structural properties are isomorphic to the structural properties of a horse *with respect to the function of riding during a particular play session*. In Gibson's terms, the hobby horse's combination of properties provides the *minimum affordance necessary to play horse-riding*.

4.3 Affordance as a basis for dogs' *interpretation*

Motamedi Fraser (2019) argues that, although they have no access to human language, dogs are able to *make words* and to transform the meaning of words by participating in non-linguistic *word encounters* with their human companions. These encounters are "*sites for experimentation, where a dog is able/enabled to create new meanings for words by bringing together potentially diverse, but nevertheless intimately familiar, resources in novel combinations*" (p.376). Thus, according to Motamedi Fraser, dogs can use their body language to make words by independently establishing new relations between familiar resources within their familiar environment based on perceived similarities, commonalities or relationships that may not be obvious to humans but that exist in the dogs' experience. The author opposes this to the situation in which dogs are conditioned to respond to words in *fixed patterns of behavior* in exchange for a reward; this type of conditioning, argues the author, turns words into stimuli, dogs' responses into reactions and dogs into machines (not dissimilar to Barbieri's primitive organisms). To elaborate, Motamedi Fraser discusses the case of a dog named Salty: during a routine retrieve exercise with her human handler, when the handler threw the familiar dumbbell for Salty to retrieve and asked her to "Fetch!", Salty retrieved a stick instead of the dumbbell. The author concludes that, by connecting the dog word 'retrieve' to a new object, Salty created a different word.

In Gombrich's terms, just as the child's hobby horse stands for a real horse, Salty's stick evidently stood for the dumbbell. Clearly, the stick had properties (possibly its *round section*, *elongated shape*, *similar dimensions*, or whatever other properties were relevant within her *Umwelt*) that made it an acceptable substitute for the dumbbell for the purpose of performing a function that was obviously relevant to her in the context of the retrieve exercise. In Peircean terms, in that context and with respect to that function, the stick's affordance was a *diagram* of the dumbbell, and the combination of properties that the stick shared with the dumbbell (making it, for example, *grab-able in the middle, hold-able by a small-angled bite, retrieve-able*) constituted the isomorphism (the *functional common denominator*) that made the substitution viable. Said isomorphism enabled Salty to *interpret* a familiar word ("Fetch!") by performing a semiotic operation that extended its meaning. At the same time, the stick's combination of properties was an *index* that signaled to Salty the object's potential for a fruitful interaction, which she evidently recognized based on her previous experience with an object (the dumbbell) that had contextually equivalent properties.

Of course, interacting with a system's interface is not the same as interacting with a static object, because in the case of a system's interface any kind of input device can be designed to produce any kind of output (e.g. a button can be used to open a door, switch on a light, play music, etc.). This raises the question as to how dogs might make sense of affordances when they interact with systems' interfaces rather than static objects. The following sections discuss how related semiotic processes might help explain this.

5 THE SEMIOTICS OF DOGS' INTERACTION WITH INTERFACES

To engage successfully with an interactive system of which he has no prior knowledge, a dog has to figure out that the system can take input and how input can be given, as well as what output the interaction might have and what the relevance of the interaction outcome might be. To say it with Norman's model, unless he knows what benefit the interaction can yield, the dog is not in a position to form the intention to complete a task and, unless he knows how to provide input, he is not in a position to decide on and implement the action sequence required to complete the task. Furthermore, unless he can perceive the output and recognize the connection between input and output, he is not in a position to evaluate the interaction (i.e. that by doing A he can make B happen). For example, a button may afford pushing, but unless pushing the button has a relevant outcome that can be related to the action of pushing, both the button's affordance and the interaction are irrelevant and, thus, meaningless which in turn makes the button's affordance harder to perceive and recognize.

In other words, the interaction with interfaces involves an *affordance chain*, or what Gaver (1991) calls *sequential affordances*: the input device itself has an affordance (e.g. a button affords being pushed) and the interaction with the input device affords an output (e.g. opening a door); the two are linked and it is in light of the latter that the former makes sense, depending on the relevance of the interaction outcome. As Gibson stresses, an affordance expresses both a *possibility* for interaction and the *benefit* of the interaction; thus, input and output, the relation between them, and the outcome of the interaction, give an affordance its meaning. The following sections examine cases of dogs' interaction with interfaces, to illustrate how the semiotic mechanisms of *indexicality* and *isomorphism* are at play, and how they are either leveraged or fail to be leveraged to support the interaction. The analyses presented below follow Peirce's abductive reasoning (Magnani 2001), according to which a limited set of observations can be interpreted based on plausibility (rather than certainty) to formulate hypotheses that may be risky but also creative and fruitful. Abductive reasoning is, thus, well-suited to the investigation of hard-to-access phenomena such as canine sensemaking, in this case, helping to derive implications for design that lend themselves to empirical validation.

5.1 Case 1: making sense of an affordance chain

As Gibson states, affordances are usually readily perceivable because they specify a benefit for the observer; but when they do not yet specify any benefit, they may only be discovered through interaction. For example, buttons afford pushing, but so do any hard surfaces; for a dog who has not evolved with buttons and is not familiar with them, a button's properties are unlikely to be meaningful until, by pushing on it, he has a chance to discover that the surface recedes under pressure and that subsequently something happens, provided he can establish an association between his action and the system's output, and that the outcome of the action has relevance for him.

In a study of canine interaction with dog-friendly controls, Mancini et al. (2016) compared two different versions: one which operated a neon light attached to a room's ceiling; and one which operated the room's motorized door. Both were large buttons of the same shape and dimensions, and featured pads of the same texture. The authors report that mobility assistance dog Ellie, the controls' user, was less successful with the light control than she was with the door control. They explain that the internal mechanism of the light control made the pad hard to press, which made the control's activation inconsistent; additionally, the neon lights took time to come on and were located out of Ellie's sight, so the effect of Ellie's action was both delayed and displaced, and thus both less perceivable and less relatable to her action. In contrast, the door control's pad was very sensitive and a gentle pressure consistently activated the door's motor; additionally, the door was located right next to the control and opened immediately. The authors conclude that the consistency of the door control's response and the space-temporal contiguity between Ellie's input and the system's output likely made it easier for her to establish a connection between the two, because the button behaved like an *index*: the space-temporal link between input and output meant that the input device's affordance soon became an indexical sign, a reliable indicator, which came to signify both an interaction opportunity and its outcome.

Furthermore, it is plausible that the relevance of the interaction outcome played a role. The increased illumination of a space already partially illuminated was likely irrelevant for Ellie, particularly considering the photo-sensitivity of canine vision. In contrast, the opening door allowed her and her human to move between rooms, including going outdoors for walks. The relevance of the interaction's outcome likely enabled her to more promptly make sense of the control's affordance.

This example suggests that both a strong indexical input-output link and a relevant interaction outcome are important for a dog to make sense of the affordance chain involved in the interaction with a system, including how to obtain a certain outcome and how to provide input to obtain it.

5.2 Case 2: evolution of sensemaking from decoding to interpreting

When a dog learns to interact with a system, the indexical relations established during the process and the relevance of the interaction outcome can enable the dog, not only to make sense of the *affordance chain* involved, but also to interpret the interaction in new ways.

Mancini and Lehtonen (2018) discuss how they trained Zena the dog to activate the above-mentioned dog-friendly control. The control opened a motorized door that was located right next to it, similar to the scenario described above. Zena had no prior knowledge of the control, which had no relevance to her, so the researchers had to enable Zena to discover its affordance by establishing a chain of indexical relations between the elements involved in the interaction. To motivate Zena to investigate the control, they initially placed a food treat on top of it such that, when Zena reached for the treat, she would automatically trigger the control causing the door to open. To invite Zena to approach the control, her handler pointed her finger (a Peircean index that dogs have been shown to understand - Bhattacharjee et al. 2020) towards the treat, just a few centimeters away, while uttering the word "Touch!". Whenever the door opened, triggered by her interaction with the control, Zena was rewarded with a treat through the open door by the other researcher and, subsequently, also by her handler.

Over several attempts, the vocal and gestural cue became a signal for the opportunity to engage in a rewarding activity defined by a series of indexical associations. Namely, placing a treat on top of the control established an indexical association between the action of retrieving the treat and the action of pushing the control's pad; the proximity and responsiveness of the door established an indexical association between the action of pushing and the opening of the door; rewarding Zena through the open door established an indexical association between the door opening and the reward delivery, making the door opening relevant for her. Eventually, this allowed the researchers to stop placing a treat on top of the control and to stop rewarding Zena through the door; instead, the handler just continued to use the cue as an invitation and to reward Zena only once the door had opened.

However, placing a treat on top of the control had created a strong bias towards 'snout interaction' and, indeed, this was how Zena continued to interact with the control even once treats were no longer placed on it. But, at one point, when the usual cue was issued, instead of using her snout to activate the control, Zena used her paw. Whatever reason (e.g. snout fatigue, frustration) there might have been for Zena's alternative choice of action, this expressed her *interpretation* of the action sequence that would enable her to realize the possibility for interaction and outcome afforded by the control. Arguably, Zena's substitution of one gesture with another marked a qualitative change in the evolution of her sensemaking. As long as she performed the task using her snout, one might assume that she was somewhat automatically *decoding* (as Barbieri might put it) a signal established through operant conditioning, or merely *reacting* (as Motamedi Fraser might put it) to the stimulus provided by the cue. However, when Zena performed the task using a new spontaneous gesture, one has to concede that she was *interpreting* (as Barbieri might say) a sign, responding flexibly to contextual conditions and thus extending her understanding of the cue, of the control's affordance and of the kind of action that could realize said affordance. The strength and reliability of the indexical relations initially established by the researchers enabled Zena to initially grasp and subsequently appropriate the meaning of the interaction and experiment with it (as Motamedi Fraser might say); and the fact that the researchers accepted her interpretation, by rewarding it, validated it within their interspecies exchange.

5.3 Case 3: interpreting and translating interaction patterns

In the example above, the action sequence that Zena had initially performed (snout interaction) and the action sequence with which she substituted it to the same effect (paw interaction) were structurally similar and functionally equivalent: regardless of the body parts involved, they were composed of the same equally ordered motion units (*targeting motion towards the control* -> *contact with the control pad* -> *application of pressure on the control pad*). This kind of isomorphism can be leveraged when designing canine interfaces to help dogs recognize the affordance of an input device and interpret the action sequence that can realize it.

Robinson et al. (2014) discuss the design process of a canine alarm that enabled medical alert dogs to summon help on behalf of their assisted humans by initiating an emergency call via the alarm's input device. This consisted of a tug that the dogs were being trained to pull to trigger the call. The action sequence involved by the interaction (*grabbing hold* -> *biting down* -> *pulling*) was similar to the 'tug-of-war' game that many dogs willingly engage in with a human partner. To help young and inexperienced dogs recognize the affordance and learn the task, initially the researchers used a large fluffy toy tug, whose structural and functional similarity to familiar toys enticed the dogs to bite and pull. As the dogs progressed and became more proficient, the initial tug was gradually substituted with smaller and more streamlined versions, whose structural and functional similarity allowed canine participants to continue to recognize the input device's affordance and correctly interpret the required interaction, seamlessly transitioning to more 'grown-up' versions of the device.

However, the 'tug-of-war' game replicates the action sequence involved in hunting behavior, which has high biological relevance, is hardwired in and is highly motivating for many dogs (according to Abrantes); in its final stage, this action sequence includes the ripping off of flesh for consumption, which in the game is afforded to the dog by the human finally letting go of the tug. As it emerged during testing with a prototype of the alarm (Robinson et al. 2014), the dogs were not contented with simply grabbing, biting and pulling the tug; they pulled it until they ripped it off its support, damaging the prototype. Thus, the isomorphism shared by the action sequences involved in a biologically relevant activity, in a game emulating the activity, and in an interaction emulating the game evidently helped the dogs to recognize the input device's affordance and interpret the action sequence that the affordance invited. But such isomorphism also produced an unexpected effect when the dogs 'translated' a relevant and familiar interaction pattern into a new context (hunting -> game -> alarm). As a result of the dogs' interpretation of the interaction, the authors resolved to design a detachable tug. The tug's detachability afforded the dogs the ability to complete a biologically relevant action sequence, thus also effectively signaling (providing feedback for) the completion of the interaction task.

5.4 Case 4: semiotic consistency, sensemaking and experience

Norman (1999) distinguishes between the *real affordances* (i.e. actual affordances) of physical objects (e.g. a button can be physically pushed) and the *perceived affordances* of virtual interfaces, signaled by representational conventions (e.g. the icon of a virtual button suggests that it can be clicked on). However, unlike with real affordances, perceived affordances may invite an interaction whose benefit cannot be actualized (e.g. when clicking on a virtual button has no outcome). In recent years, an increasing number of on-screen games targeted at dogs have appeared on the pet market, typically featuring icons of small animals moving across the screen for canine players to chase. Zamansky et al. (2017) conducted a study to assess human perceptions of such interactions, examining videos of dogs interacting with on-screen games that featured moving objects. These consistently elicited hunting behavior patterns and the authors warn that for many dogs the interactions were overstimulating, frustrating and stressful, with videos showing some of them frantically pawing at the screen, pouncing on and even biting the displaying device.

This might be described as the result of *semiotic inconsistency*, whereby important aspects of a representation signal an affordance that fails to be confirmed by other related aspects and to be realized. In this case, the behavior of a virtual object, whose motion was isomorphic to that of a prey animal, specified an affordance (*chase-ability* + *catch-ability*) that had strong biological relevance (chasing and catching prey). However, as the dogs reacted to a powerful indexical sign and attempted to interact with the moving object to actualize the perceived affordance, the lack of haptic feedback from the object and its unresponsiveness to the dogs' actions contradicted the sign provided by its motion and ultimately denied the affordance. Suddenly, the object no longer qualified as an acceptable substitute, failing to yield the suggested interaction outcome. This is somewhat akin to what Gibson describes as misperceived affordances, as though the dogs attempted to walk through a (metaphorical) 'glass door' only to (metaphorically) 'smash their faces' into the glass.

Very differently, the on-screen game Wallis et al. (2017) developed to provide cognitive stimulation for aging dogs featured simple abstract shapes appearing randomly on a screen. By initially placing peanut butter on the screen where the shapes appeared, the researchers helped the dogs establish an indexical association between the shapes and the butter, thus turning the shapes into powerful indexical signs. Once the dogs had made the association, whenever they touched the shapes with their snout, these disappeared (as though they might have been swallowed) and, right underneath the screen, the system automatically delivered a food treat, which now substituted the butter. Thus, by indexical association, the dogs learnt to perceive in the virtual shapes an affordance (*touch-ability* -> *catch-ability*) that was reliably actualized by the outcome of the interaction in the form of treats. In this game, the 'catching' of virtual objects delivered a tangible and highly relevant interaction with a food reward, all the while exercising the cognitive abilities of the dogs. Sure enough, unlike with the dogs studied by Zamansky et al. (2017), Wallis et al. (2017) report a very positive response from their canine participants.

6 THE SEMIOTICS OF AFFORDANCE IN PRACTICE: IMPLICATIONS FOR DESIGN

The analysis of the above examples illustrates how a dog's interaction with an interface requires him to make sense of an affordance chain, where the meaning of the affordance of an input device derives from the outcome of the interaction. This meaning is given by the indexical relations that enable the dog to establish a connection between his action and the resulting outcome; and by the indexical and diagrammatical relations that enable the dog to recognize and interpret the affordance relative to his previous experience and current motivations, and the functions these serve within his *Umwelt*.

There is a good reason why *indexes* and *diagrams* are fundamentally implicated in the semiotics of affordance. Unlike *symbols*, *images* and *metaphors* - which are grounded in culturally dependent representational conventions and imply species-specific capabilities of perception and abstraction - *indexes* are contextually established and have a concrete and 'necessary' relation to the object they represent (Kohn 2010); this makes them reliable signals that any organism capable of associative learning can *interpret* or at least *decode*. Similarly, *diagrams* capture the structure of the object they represent; in the case of affordances, this structure corresponds to the invariant combination of properties that signal a potential for and benefit of interaction, which any organism for whom the interaction has biological relevance can *recognize* or at least *discover*.

This is not to say that dogs would not be able to interact with interfaces that make use of other signs, such as symbols or images. However, indexicality and isomorphism are arguably the most fundamental mechanisms that underpin dogs' sensemaking of such interactions. Therefore, to begin with, the design of canine-centered interfaces should carefully consider these semiotic mechanisms and related implications. In particular, the analyses presented above suggest the following implications for design:

- When a dog encounters an interface for the first time and has no awareness of the benefit specified by the affordance of an input device, the strength of the indexical relation (i.e. space-temporal proximity) between his input and the system's output, and the high relevance of the interaction's outcome (i.e. any output and associated benefits) are likely to enable the dog to promptly recognize the affordance and make sense of the interaction.
- When an affordance is already meaningful for a dog, because he has experienced it before or because it leverages an isomorphism with a known affordance, these existing associations are likely to influence how the dog makes sense of the interaction and how he is inclined to interact with the input device.
- When the affordance of an input device leverages an isomorphism with a familiar and biologically relevant affordance, the dog is likely to interpret it accordingly and to perform an action sequence whose goal is to realize the familiar affordance; a device that allows the dog to provide input by performing the action

sequence in its completeness is more likely to help him make sense of the interaction, including understanding when the input task has been completed.

- An input device which allows a dog to actualize its affordance by performing different (i.e. non-identical), albeit structurally similar and functionally equivalent, action sequences is more likely to encourage a dog to interpret and appropriate the interaction; in turn, this may provide an indication of his learning progress and of his preferred input modality for the interaction in question.
- An interface which, by isomorphism with biologically relevant affordances, signals an affordance that fails to be confirmed by related signals and that cannot be realized produces a semiotic inconsistency that is likely to frustrate the dog's biological drives and his ability to make sense of the interaction; in contrast, an interface that signals and realizes an affordance in a way that is consistent with and equivalent to the biological processes it replicates is likely to enable the dog's sensemaking and provide him satisfaction.

These insights are consistent both with the behaviorist rules of associative learning and with the cognitive interaction model discussed above, and frequently referred to in ACI research and design. However, taking a semiotic perspective allows us to go further and question the mechanisms that may underpin dogs' sensemaking. Although, consistent with the rules of associative learning, indexical relations are implicated in dogs' sensemaking of affordance, indexicality is not the only mechanism involved and is at play in connection with the mechanism of isomorphism, which behaviorist rules do not account for. At the same time, the cognitive approach to interaction has had little to say on exactly how the different forms of iconicity (and other sign relations) are implicated in the sensemaking of affordance. Thus, while the cognitive approach has been useful to broadly conceptualize dogs' interaction with interfaces and the behaviorist approach has been useful to teach dogs how to interact with them and test their usability, neither approach has helped researchers predict what designs might better support canine sensemaking and informed the principled design of affordance chains that are most likely to make sense for dogs. The semiotic approach proposed here attempts to fill this gap by accounting for the sign relations that are likely to be implicated in how dogs make sense of affordances and establish affordance chains, to help researchers predict what kind of interfaces might better support canine sensemaking. The aim is not to second-guess what canine users might be thinking, but rather to help explain *how* certain connections may be forged (as Motamedi Fraser puts it) and how canine signification may work in this context; the aim is not to imagine what dogs' *Umwelt* of an interactive system might be like, but rather to question what mechanisms might inform it, so that such mechanisms may be leveraged to design interfaces that support dogs' sensemaking process.

Figure 1 and Table 1 present a framework aiming to help designers analyze and design dogs' interactions with interfaces from a semiotic perspective. Figure 1 illustrates the interrelated elements that may inform a dog's sensemaking of and interaction with a system, and that need to be considered when designing a canine interface. Table 1 suggests questions that could help designers consider relevant design variables, and possible trade-offs between them, to best support a dog's sensemaking and interaction. For example, the greater the spatial distance between an input device and the system's output, the more obviously perceivable the interaction outcome might need to be; the less familiar and recognizable an affordance, the more promptly and reliably the output might need to follow the input; the less reliable the input-output connection, the greater the relevance of the interaction outcome might need to be.

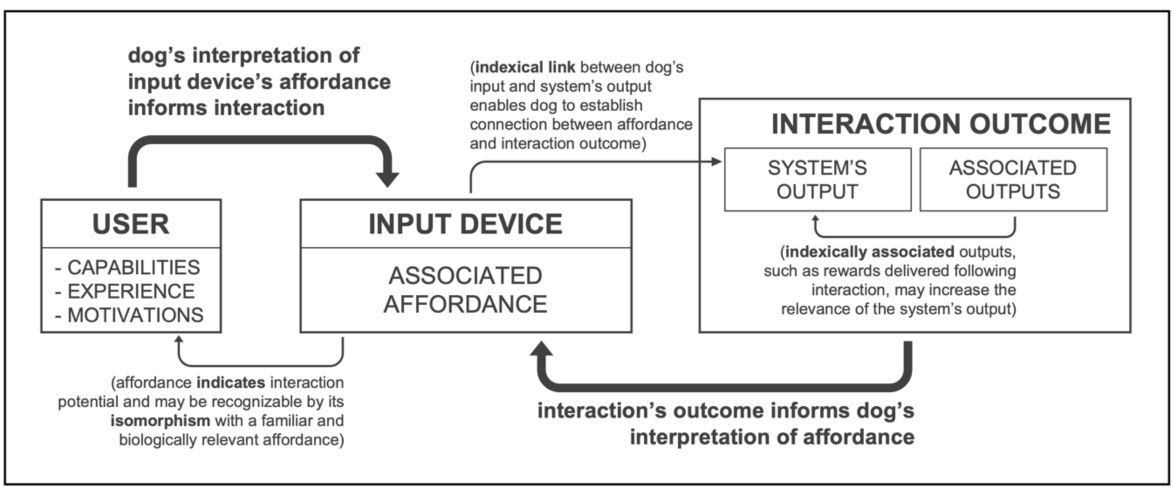

Figure 1 - Elements informing dogs' sensemaking of and interaction with a system, to consider when designing a canine interface

Table 1 - Questions regarding design variables, and possible trade-offs between them, to consider for supporting dogs' sensemaking and interaction

KEY COMPONENTS OF AN INTERFACE AND RELATED DESIGN VARIABLES		
AFFORDANCE	INPUT-OUTPUT RELATION	OUTCOME
interaction that the input device affords and which produces an output	strength of the indexical relation between input and output	outcome that the interaction affords which results from the input
EXAMPLES OF QUESTIONS **regarding design variables, and possible trade-offs between them,** **which may inform dogs' sensemaking of an affordance and of the interaction with an interface.**		
• Is the input device familiar to the dog? • Does the input device's affordance leverage an isomorphism with a familiar affordance? • Does the isomorphism leveraged by the input device relate to an activity that fulfils of a biological drive? • Can the input device's affordance be actualized through the same action sequence the dog would perform to fulfil the drive? • Can the input device's affordance be actualized by different, albeit isomorphic, action sequences?	• How reliably does the output follow the input? • With what level of precision must the input be provided in order to produce an output? • What is the spatial distance between input and output? • What is the temporal distance between input and output?	• Can the outcome specified by the affordance be achieved by the dog? • Can the outcome afforded by the interaction be perceived by the dog? • Is the outcome afforded by the interaction relevant for the dog? • Is the outcome consistent with the action sequence invited by the affordance?

7 CONCLUDING REMARKS

This paper builds on biosemiotics theories to propose a framework that could help researchers analyze dogs' interaction with interfaces and support the design of canine-centered systems. The purpose of the paper is by no means to draw conclusions on dogs' sensemaking. Rather, in the spirit of Peircean abductive reasoning, the paper uses example case studies to articulate how basic sensemaking mechanisms might underpin canine interactions and how they could be leveraged by canine interfaces. The variables of the proposed framework could be manipulated to inform hypotheses about dogs' sensemaking during interaction with interfaces. These could be used to inform the design of canine interfaces and empirically tested to validate the proposed framework based on dogs' responses to the resulting designs. For example, future studies could systematically explore how diverse input-output space-temporal relations (e.g. changes in feedback timing), variations in the relevance of interaction outcomes (e.g. changes in reward levels and other benefits) and different training approaches (e.g. *luring* vs *shaping* - Handelman 2008 – vs *do as I do* – Fugazza 2014) might affect the dogs' ability to establish indexical connections and grasp affordance chains. Other studies could further explore the role of isomorphism, with regards to the recognition of input devices (e.g. to identify what formal variations make an input device more or less recognizable) and to the execution of tasks (e.g. to identify the variations of an action sequence that an input device might need to accommodate). To this end, different interfaces, some of which designed according to the proposed framework, could be proposed to dogs providing them with different levels of training, to see which designs they could understand with little or no conditioning.

However, while it focuses on dogs, the framework accounts for the most fundamental semiotic mechanisms implicated in interaction and, thus, could plausibly support the analysis and design of animal-centered interactions more broadly. It could also be extended to account for more complex semiotic processes that might be relevant for other species. On this trajectory, the purpose of this paper is to offer a lens through which to approach the grand-challenge of animal-centered interaction design. As Mancini and Lehtonen (2018) point out, "*interaction design can be seen as a process of incremental orientation towards an optimal final outcome that may never be reached, but that can be approximated*" (p.914). This paper's contribution is to show how a 'biosemiotics compass' could help orient designers during the process, and to offer an analytical and design framework that could be further developed and improved going forward.

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According to Nussbaum (2006)'s philosophy of multispecies justice, animals are autonomous agents capable of dignified existence and, thus, are morally entitled to pursuing species-specific capabilities, including continuing to live, maintaining bodily health and integrity, accessing important resources, engaging in meaningful activities and interactions, and attaining their own excellence through dignified work. Arguably, in order to pursue their capabilities, animals need to be able to make sense of their environment. However, this can be hard to do in an anthropocentrically technologized world to which they are not adapted. As Rowlands (2008) puts it, animals who live among humans, such as dogs, live "*in a magical world"* (p.29), rather than the mechanical world for which the intelligence of animals who do not live among humans, such as wolves, has evolved. In such a magical world, Rowlands points out, animals have little control over their environment and depend on humans to interact with it effectively, which inevitably frustrates the autonomous pursuit of their capabilities. Designing animal-centered systems means taking some of the 'nonsensical' magic out of this technologized world in order to restore some of animals' autonomy and dignity. As Mancini et al. (2022) discuss, designing animal-centered systems is more than just designing interfaces and requires considering the many different, direct and indirect, ways in which animals may come into contact with or be affected by technology. Nevertheless, designing animal-centered interfaces is an essential part of the thrust. Whatever form they might take, *inter-faces* (the faces in between), are what mediates our interaction with systems and, through them, with the world beyond. Therefore, striving to design interfaces that dogs and other animals can make sense of and, thus, interact with could enable them to interact with the world, not as conditioned machines or mere experimental subjects (Motamedi Fraser 2019), but as autonomous agents capable of pursuing their own goals, of carrying out dignified work safely and effectively, and of expressing natural behaviors (e.g. play), within environments they can understand and benefit from. This is, after all, a fundamental ambition of ACI (Mancini 2011).

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