
TOWARDS A 4E APPROACH TO CANINE OLFACTION

THEORETICAL PERSPECTIVE

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ABSTRACT

4E Cognition is an emerging theory that holds that the core processes of cognition are not limited to the brain. This paper makes an argument for viewing olfaction, and specifically canine olfaction, through a 4E lens. In the process, a novel synthesis of several fields, topics, and facts is produced that allows for the creation of a new direction of inquiry for cognitive science as a whole, with the domestic dog and olfaction as exciting comparative models of study.

Keywords olfaction · canine · 4E Cognition

1 A Primer on 4E Cognition

1.1 Background and History

“The world is not an object such that I have in my possession the law of its making; it is the natural setting of, and field for, all my thoughts and all my explicit perceptions.” - Merleau-Ponty, *Phenomenology of Perception* Merleau-Ponty [1962]

“There does not exist anything That is not dependently arisen.” - Nāgārjuna, *Mūlamadhyamakakārikā* Nāgārjuna and L.

A central preoccupation for philosophers across cultures and millennia has been the nature of the relationship between mind and world. Continuing to vex thinkers today, the so-called ‘mind-body problem’ remains an outstanding unsolved problem in the sciences of cognition and consciousness and revolves around the seemingly irreconcilable split of the objective material world and the subjective mental world. The historical source of this split is often traced back to Descartes’ infamous articulation, made to protect science from the persecution of the Church, where he deemed the domain of science to explicitly be about the material world (*res extensa*), while mental phenomena (*res cogitans*) was under the purview of religion Kelly and Marshall [2021]. This Cartesian dualism proved influential in fostering the impression that the mind could be understood without any reference to the external world. As the 1950’s ushered in the new field of cognitive science, the mind-world dichotomy was baked into the dominant paradigm - cognitivism - that held cognition to be akin to “information processing that consists in the syntactically driven manipulation of representational mental structures” (Barrett [2018], p.3).

Crucially, this information processing is assumed to take place in an abstract and amodal plane consisting of symbolic or sub-symbolic processes that are localized in the brain. It naturally follows from this that understanding any cognitive process requires only an understanding of the brain process that gave rise to it, with the body of the cognitive agent and the environment it is situated in mattering only for the provision of stimuli, flesh-and-bone housing, and a material mass to maneuver around. This perspective is evident and indeed partly emerged from the developments in the field of Artificial Intelligence, where intelligence - human or otherwise - comes to so resemble “computation in its essential characteristics that cognition can actually be defined as computations of symbolic representations.” (Varela et al. [2016], p.47)

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Emerging in response to this cognitivist paradigm, the field of 4E Cognition arrived on the scene in the 1990's, with the watershed moment being the publication of the seminal book *The Embodied Mind* by Francisco Varela, Evan Thompson and Eleanor Rosch Varela et al. [2016]. The authors draw upon Western lineages such as the phenomenology of Husserl and Merleau-Ponty, as well as Buddhist scholarship such as the non-dualism of the Madhyamika philosophy of Nagarjuna, and propose a reconciliation of the biological-outer and the phenomenological-inner worlds. This reconciliation is centered around the recognition of the circularity and enfolding inherent in the mind-world relationship and emphasizes the dynamic coupling of brain-body-environment crystallized in the idea of 'embodied action'.

Here, embodied is being used to refer to both the ways cognition is dependent, and even constituted, by the bodily experiences engendered by sensorimotor capacities and how these sensorimotor structures are themselves embedded in a larger context of biological, psychological, and cultural dimensions. Meanwhile, action is used to refer to the interrelation and indeed, inseparability, of perception and action, with 'enactive' coming to mean the process by which recurrent sensorimotor patterns that perceptually guide action end up creating the cognitive structures that allow for perception in the first place. Or as Alva Noë puts it - "Perception is not something that happens to us, or in us. It is something we do." Noë [2004]

Around the same time and following *The Embodied Mind*, other accounts were proposed that refuted the core tenets of cognitivism. Walter Freeman drew upon the philosophy of Aquinas and his empirical work on olfaction to propose a model of mind he called pragmatism, in opposition to views of materialism and cognitivism, that construe minds as "dynamic structures that result from actions in the world" and that "the body and the brain are open systems with through-put of matter, energy, and information" Freeman [2000], p.28). Andy Clark and David Chalmers argued in their 1998 essay *The Extended Mind* for an 'active externalism' where cognition, mind, and even self extend beyond the confines of skull and skin through the active role of the environment in driving cognitive processes Clark and Chalmers' [1998]. Finally, concepts of ecological psychology pioneered by J. J. Gibson, such as affordances — construed as the main objects of perception that contain the possibilities of action in the environment Gibson [1979], Lobo et al. [2018] — began to mature and radiate outwards in the cognitive sciences. The end result at the turn of the new millennium was the emergence of a motley collection of cognitive theories that, despite having somewhat contradictory claims, were nevertheless unified in their opposition to behaviorist/cognitivist paradigms and their commitment to the importance of the body and its dynamic coupling with the environment in understanding cognition. The umbrella term for these theories has come to be called 4E Cognition, with the E's standing for Embodied, Enacted, Embedded and Extended.

1.2 Elucidating the E's - Definitions and Differences

Given the overarching nature of the term, it becomes vital to define and differentiate the different theories at play in 4E Cognition. The following is a succinct summary of the account provided by the 2018 Oxford Handbook of 4E Cognition Barrett [2018].

The key idea bridging the four E's — Embodied, Enacted, Embedded, and Extended — is that cognition involves extracranial processes. However, what this means varies depending on the precise reading of the words 'involves' and 'extracranial'.

First, the involvement of extracranial processes can come in two flavors - strong and weak. Strong involvement posits that cognitive processes are partially constituted by extracranial processes whereas weak involvement posits that cognitive processes are causally dependent on extracranial processes.

Second, extracranial can refer to two things - bodily and extrabodily. Bodily refers to the brain-body unit while extrabodily refers to the brain-body-environment nexus.

Hence, you have four possible understandings of cognition involving extracranial processes -

1. Weak bodily embodiment is when a cognitive process is causally dependent on bodily processes.
2. Strong bodily embodiment is when a cognitive process is partially constituted by bodily processes.
3. Weak extrabodily embodiment is when a cognitive process is causally dependent on extrabodily processes.
4. Strong extrabodily embodiment is when a cognitive process is partially constituted by extrabodily processes.

Embedded Cognition is equivalent to 3 - weak extrabodily embodiment. Extended Cognition is equivalent to 4 - strong extrabodily embodiment. A cognitive process does not necessarily have to be either Extended or Embedded as a process can involve more than one extracranial coupling. This will become especially relevant when we arrive at canine olfaction, as we shall soon see.

Finally, extracranial processes can also refer to the agent's active engagement with and within an environment. This ability or disposition to act is posited to be involved with cognitive processes - leading to the fourth E - Enacted

Cognition. As before, this involvement can be read as either strong or weak - referring again to the constitution vs causal dependence distinction. Philosophical clarity on the exact nature of this distinction remains an unresolved problem and is out-of-scope for this paper Barrett [2018].

The definition this paper will be using is as follows — A feature f is constitutive for a pattern X if it is part of at least one set of features which is minimally sufficient for a token to belong to a type X . “Minimally sufficient” means that these features are jointly sufficient for the episode to be of type X , but if one of them would be taken away the episode would not count as an instance of type X anymore Gallagher [2013].

1.3 Going Radical

The stakes of adopting E-approaches to cognition can go beyond pinning the locus of cognition, but only if one takes the strong reading of embodiment and enactment. This is because in strong or ‘radical’ readings - we are forced to fundamentally rethink how the brain works. Cognitivism ‘represents’ cognition as “the mind represents and computes” (Branquinho [2001], xv) and invariably ends up adopting representationalism and computationalism as fundamental pillars. On the other hand, radical 4E approaches - dubbed as radically enactive and embodied accounts of cognition (REC) - eschew the notion of representation altogether — “the brain . . . responds to the world rather than represents it. Specifically, it responds not by representing, but through a dynamical participation in a large range of messy adjustments and readjustments that involve internal homeostasis, external appropriation and accommodation, and larger sets of normative practices.” Gallagher [2018]. In other words, “REC understands cognition as something that organisms do.” and that cognition is best understood as “unfolding, world-relating processes rather than in terms of content-bearing states and their interactions.” (Hutto and Myin [2018], p. 3)

The implications of the REC approach to understanding cognition are therefore profound and entail a complete overhaul of our frameworks related to perception, memory, learning, and sense-making —

- Perception is no longer about formulating adequate representations of real-world objects and events but is instead a drive to acquire or maintain a flexible grip on the world.
- Memory is no longer about the storage of discrete, abstract units of co-varying information but instead is transformed into ‘embodied know-how’ that can be understood as the “overall responsiveness of a complex system that is laid down through habit and past experience.” Barandiaran and Di Paolo.
- Learning, thus, no longer requires the generalization and interiorization of abstract principles from specific cases and instead can be conceptualized as an itinerant trajectory over a landscape of limit cycle attractors with adjoining basis of attractions, and the attractors are “not shaped by the stimuli directly, but by previous experience with those stimuli, which includes preafferent signals and neuromodulators as well as sensory input.” (Freeman [2000], p.62) Put another way, “there are no fixed representations, as there are in computers; there are only meanings” (Freeman [2000], p.22) and this meaning is continuously shifting and evolving.

Ultimately, REC shifts the conception of cognition from accurately representing an environment to “continuously engaging that environment with a body so as to stabilize appropriate coordinated patterns of behavior.” (Beer [2000], p.97) By going radical, the cognitive scientist interested in perception is no longer concerned with how an independent ‘no one around to hear’ world is to be recovered from abstract representations but instead cares about the underlying linkages between sensory and motor systems that explain how “action can be perceptually guided in a perceiver-dependent world.” (Varela et al. [2016], p.173)

This radical approach will be embraced with open arms (and paws) in this paper in an attempt to provide a revitalized framework for understanding canine olfaction. However, it is necessary to pay heed to a criticism levied at 4E approaches, recently articulated by Miłkowski and colleagues Miłkowski et al. [2018], that such approaches tend to be nothing more than “abstract heuristics that cannot do much explanatory work in isolation”. The authors stress that 4E approaches will only be useful if taken in conjunction and applied with building mechanistic models that can be further tested and refined in constrained systems with physiological, neurological and psychological evidence. This important critique is duly noted and informs the formulation of experimental protocols later on.

Now, we turn our attention over to the ancient and mysterious sense of olfaction. The focus here will be outlining the key features of olfaction that make it particularly relevant to 4E approaches. As such, special attention will be paid to its evolutionary underpinnings, which will consequently lead us to olfaction’s intimate relation with spatial navigation. The section will end with a brief note highlighting why olfaction is the right question to ground and orient 4E approaches to cognition.

2 Searching for the E in Smell

2.1 Current Understanding of Olfaction

“I should think we might fairly gauge the future of biological science, centuries ahead, by estimating the time it will take to reach a complete, comprehensive understanding of odor. It may not seem a profound enough problem to dominate all the life sciences, but it contains, piece by piece, all the mysteries” Lewis Thomson Thomas [1995]

Despite the ubiquity, universal importance in animals, and deep evolutionary history Ache and Young [2005], our understanding of olfaction remains profoundly incomplete. The advent of new technologies like eNoses Snitz et al. [2021] and olfactory virtual realities Harvey et al. [2009] and substantial empirical progress such as the creation of predictive models to design non-overlapping molecular compositions that generate identical odor precepts, Ravia et al. [2020] has yet to answer major questions. These include the fundamental questions of the nature of the olfactory code - the relation between the structure of odorant molecules, olfactory receptors and perception - and the organization of olfactory maps in the brain Murthy [2011], Jacobs [2021].

A vastly simplified sketch of our olfactory knowledge in vertebrates goes thus. The two main olfactory systems are the main olfactory system (MOS) and the vomeronasal system (VNS). The VNS has two distinct types of vomeronasal receptors that appear to be concerned with ligands related to social cues - pheromones - although this is not uniformly true for all mammals and little is known about their mechanism of action Kaupp [2010], Baxi et al. [2006]. The MOS is housed in the mucous membrane of the roof of the nasal cavity and consists of an olfactory epithelium flush with olfactory sensory neurons (OSNs). OSNs express a family of olfactory receptors (ORs) that can bind to small volatile molecules ‘odorants’. Every OSN expresses only one type of OR. ORs are a highly diverse group of G-protein coupled receptors (GPCRs) and are encoded by a large repertoire of genes - ranging from 125 - 2129 - with most species having between 600-1300 OR genes Kaupp [2010]. Odorants binding to ORs in OSNs are transduced to electrical activity and projected through axons to anatomical structures called glomeruli on the surface of the olfactory bulb (OB). A tremendous convergence and divergence takes place at the glomeruli, as OSNs can project to many thousands of glomeruli, and glomeruli in turn can receive projections from hundreds of OSNs. Axons from the glomeruli form the olfactory nerve and project to the primary olfactory cortex, or pyriform cortex. The pyriform cortex then projects to multiple different brain regions including the orbitofrontal cortex, the hypothalamus, the amygdala, and the hippocampus Murthy [2011], Gazzaniga et al. [2019].

Before moving on to olfaction’s evolutionary origins, a final factor in olfaction crucial to mention is the role of the sniff. Noam Sobel pioneered some of the early research showing that the sniff was a part of the olfactory percept, as integral to olfactory perception as eye movement is to visual perception. The sniff is necessary and sufficient for generating activity in the olfactory cortex as well as being necessary and sufficient for olfactory perception Mainland and Sobel [2006], Kepecs et al. [2006]. This point will become vital when we come to Canine Olfaction as Enacted.

But before that, onwards to the past.

2.2 Finding the E in Evolution

“Nothing in biology makes sense except in light of evolution” Theodosius Dobzhansky, 1973 ? “4E cognition thus offers an alternative to the anthropogenic approach, by providing a bottom-up or “biogenic” perspective on cognitive evolution, where the principles of biological organization, and their links to fitness, are taken to be the most productive means by which we can understand what cognition is, what it does, and how and why it evolved.” - The Evolution of Cognition : A 4E Approach Barrett [2018]

To begin to formulate a 4E approach to olfaction it is necessary to first understand some of olfaction’s evolutionary underpinnings. This is because 4E frameworks ground notions of cognition in the multiple ways an organism and their environment are mutually enfolded and so “what constitutes the world of a given organism is enacted by that organism’s history of structural coupling.” (Varela et al. [2016], pg.202). This structured coupling is temporally thick and extends back the phylogenetic tree, thus, a complete understanding of any organism’s cognitive process requires grasping the history and nature of this coupling.

Evolution is of particular importance when it comes to olfaction because of its universal nature. Olfaction relies on chemicals and chemicals are readily available to be used as stimuli because they do not require a transduction step. Hence, it is likely that all organisms make use of chemicals - ranging in manner from the runs and tumbles of *E.coli* to the complex navigation performed by search and rescue dogs Dusenbery [1992].

Olfaction also has deep ties with spatial navigation. This implies that the elemental and archetypal need for animals to orient in space to find food and avoid predators is contingent on its ability to smell. The ties between olfaction, spatial

navigation, and memory are the subject of a set of intriguing theories proposed by Lucia Jacobs that are necessary to explicate in some detail and are summarized in her recent 2021 paper Jacobs [2021].

The olfactory spatial (OS) hypothesis Jacobs [2012] offers an explanation for the curious pattern observed in vertebrate brain evolution, where the size of the olfactory bulb scales independently from the size of the brain as a whole. The OS hypothesis proposes that this scaling reflects differential selection pressures on animals in their need to decode and map patterns of odors that vary with their need for spatial navigation. The crux of the OS hypothesis lies in two findings from the olfactory literature — a) the same odorant can be perceived as categorically different depending on its concentration and b) odorant mixtures can be perceived as combinations of elemental odors or as a non-decomposable synthetic odor object. Taken together, these findings allow for the creation of a low resolution olfactory elemental map based on demarcations from single odorants and a high resolution object map based on combinations of odors. Animals can flexibly between these maps depending on their needs. This dual-map parallels, and may even precede, the ‘parallel map’ structure of the hippocampus proposed by Jacobs and Schenk Jacobs and Schenk [2003], with the bearing-map analogous to the elemental map and the sketch-map analogous to the synthetic object map. Jacobs advances the argument that these maps could have been the substrate for associative learning and the foundation for the evolution of memory organization.

The perceiving and reconstructing odor utility in space and time (PROUST) hypothesis seeks to explain the curious emergence of the vomeronasal (VNS) olfactory sub-system in vertebrates, when the main olfactory system (MOS) was already prevalent. PROUST proposes a disassociation between the function of the MOS and the VNS, predicting the MOS would be involved with directional olfaction - determining the distribution of an odor in space, while the VNS would be involved in diagnosis olfaction - determining the functional identity of an odor. Notably, the VNS affords itself to biotic odors with larger non-volatile molecules, as the VNS depends on molecules being transported through the saliva, and tends to be used by vertebrates to diagnose a biotic’s agent physiological state, including disease Kavaliers et al. [2020].

Finally, Jacobs provides an underlying mechanism for the relationship between nasal respiration and olfaction. A spate of recent studies have indicated that nasal respiration entrains fundamental cognitive processes, through theta oscillations that synchronize a variety of dispersed brain networks, that result in profound effects on memory, among other processes. Tort et al. [2018, 2021], Yanovsky et al. [2014], Zelano et al. [2016]. Jacobs proposes that theta waves could act as the pacemaker for marking distance when animals embark on the collection of sniff samples along a gradient in the olfactory spatial hypothesis. Thus, species differences in theta could be attributed to their ecological niche following ethological rules. This is evidenced in the distribution of two types of theta differentiated by their relative frequency - Type 1 theta and Type 2 theta. Type 1 theta is expressed when the animal is in continuous motion whereas Type 2 theta is expressed when the animal is stationary. Hence, we would expect predators like the dog, that depend on orienting to olfactory cues to track prey, to preferentially express Type 1 theta; whereas predators like the cat, that remain stationary in ambushes, to preferentially express Type 2 theta. This is precisely what we see Jacobs [2021].

We are now in a position to advance a linkage between the 4E and olfactory realms. As we have seen, olfactory perception plays a vital role in both the construction and the navigation of an organism’s spatial maps. Construction and navigation are circularly enmeshed – to construct the elemental odor map requires the navigation along the odor gradient, which itself relies on the prior construction of both the elemental and synthetic object maps. Olfactory perception and spatial navigation are thus prototypical examples of the dynamic enactive coupling of action-perception, of Noë’s “perception is what we do”. What is more, we have good reason to believe from empirical work done by Freeman, that the olfactory percept itself is constructed using information gained from spatial navigation. As Freeman puts it “Conceiving the source is part of the meaning of the odor. To do this, the animal needs to know where it was when it perceived the odor, and needs to keep a record of how strong it was.” (Freeman [2000], 19) It naturally follows from this that a representationalist paradigm that seeks to derive a relationship between an odorant and its evoked behavior through an isolated abstract representation will fail, and indeed, this is what Jacobs suggests is the reason for the olfactory code remaining uncracked Jacobs [2012]. What is needed is an account that fully embraces the ways olfaction is performed by the entire organism in a dynamic dance with the environment. This embrace starts with an E.

2.3 Olfaction as the right question

“Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made more precise” John Tukey, *The Future of Data Analysis* Tukey [1962]

Despite the strong linkage with 4E paradigms, olfaction has been critically understudied by the field. But it’s not just 4E, olfaction has been understudied by the cognitive sciences in general. A big part of this is likely the way sapien scientists are “blinded by vision” Jacobs [2021]. A more pragmatic reason is that experiments involving olfactory stimuli can be technologically tricky to pull off Gazzaniga et al. [2019].

Yet, we have good reason to believe that understanding olfaction could pave the way for developing better models for understanding other sensory systems. Freeman states this explicitly by claiming that "intentionality first emerged in the olfactory system", and the other sensory systems - vision, audition and touch - "moved in and co-opted the operating system, changing the details but taking advantage of the main thrust of the dynamics". Freeman goes on to make the even stronger claim that "we will not understand vision and hearing, including spoken and visual forms of representation, until we know how our brains cope with the infinite complexities of our olfactory environment." Freeman [2000]

Jacobs arrives at a similar position, albeit from an evolutionary perspective. Starting with John Tukey's view that approximate answers to the right question are better than exact answers to the wrong question, she notes how the trilemma of the function of the hippocampus, spatial navigation, and olfaction are the right questions, and ends with the stirring claim that "Understanding the evolutionary history of spatial orientation to odours could well provide a blueprint for the evolution of cognition itself." (Jacobs [2021], 9)

3 Let The Dogs Out

3.1 Human Meets Canine

"Relations are constitutive; dogs and people are emergent as historical beings, as subjects and objects to each other, precisely through the verbs of their relating." - Donna Haraway, *When Species Meet* (Haraway [2008], pg.62)

With estimates for when dogs likely diverged from wolves ranging from 135,000 Vilà et al. [1997] to 14,000 years Larson et al. [2012], and a 2013 estimate of 900 million dogs romping on Planet Earth, Gompper [2013] the canine-human matrix has a long and storied history awash with furry complexity. From hunters, retrievers and security enforcers, workers in farms, airports and rescue operations, companions, therapists and even doctors, the roles dogs play in our societies, both ancient and modern, are varied and all-encompassing.

As Haraway elucidates, the relations that dogs and humans enter into are forges that form and shape their very identities of being and becoming and as such behoove an intentionality of respect and a capacity for response. Crucially, Haraway points out that "Such a capacity can be shaped only in and for multidirectional relationships" and that both humans and dogs must bear responsibility to tending to their relations, although such response-ability need not be symmetric, and if "this structure of material-semiotic relating breaks down or is not permitted to be born, then nothing but objectification and oppression remains." (Haraway [2008], p. 71)

3.2 Canine Medical Intuities

The ability of dogs to detect disease in humans has garnered much buzz, especially after evidence has accrued that they are capable of detecting SARS-COV-2 in real-time with a high degree of accuracy, sometimes greater than even the PCR test used to test their detection validity Dickey and Junqueira [2021], Eskandari et al. [2021], Hag-Ali et al. [2021], Otto et al. [2021].

The hypothesis that dogs may be capable of detecting disease was first formally put forth by Williams and Pembroke in a letter to the *Lancet* in 1989, based on anecdotal evidence from a patient whose dog kept sniffing at a mole that ended up being diagnosed as malignant Williams and Pembroke [1989]. The first experiment to formally test the disease detection ability of canines was conducted in 2004, where 7 dogs performed much higher than chance in detecting bladder cancer from urine samples Willis et al. [2004].

Since then, canine diagnosis has been tested in at least 16 different types of diseases - in humans, canines, bovines and even trees - summarized in the table on the next page. As readily apparent from the number of dogs tested, these experiments have tended to be small exploratory studies and canine diagnosis has not been used in the field apart from a few instances of Covid-19 testing at airports and stadiums. This is primarily because of the 'black box' nature of diagnosis which precludes the standardization necessary for public health regulations.

The promise of a canine public health task force cannot be underestimated. There is immense potential for bolstering biosecurity and future pandemic preparation, eradicating public health menaces like malaria, and vastly expanding early life-saving diagnoses of cancers. What is needed is a richer understanding of the canine olfactory process that allows them (and us) to detect disease.

3.3 Dognosis — Dog noses

In their 1989 *Lancet* letter, authors Williams and Pembroke hypothesized that the dog was able to detect her guardian's melanoma because of the unique odors emitted by the aberrant protein synthesis caused by the malignancy. This

hypothesis has now been extended and formalized to explain the vast array of diseases that dogs seem capable of detecting. It goes like this. Every organism undergoes cellular metabolic processes that produce by-products. Some of these by-products are low molecular weight compounds that exit the body via the air, skin, blood, or liquid/solid waste products. These volatile organic compounds (VOC) are collectively called the volatilome. In a diseased condition, the volatilome appears to change in a disease-contingent manner. With their remarkable olfactory acuity, dogs are capable of detecting these shifts and can be trained to identify them across individuals Angle et al. [2016].

In the studies reviewed above, disease detection dogs generally underwent a training and a test phase. Training involved positive reinforcement and clicker shaping to train dogs to learn to identify target odors and indicate their location to their handlers using behavioral cues such as standing and staring, sitting down, or pressing their snout against the odor container. Some of the more recent studies Jendryn et al. [2021] used canine training aids such as the 'Detection Dog Training System' (DDTS; Kynoscience UG, Germany). Crucially, all studies depend on the dogs indicating odor locations to their handlers for successful identifications.

3.4 Canis Familiaris as the right model

Previously, we introduced the critique of 4E-approaches that claimed such theories offered little substantive value in deciphering cognitive processes in the absence of models that could provide concrete evidence for defined mechanisms Miłkowski et al. [2018]. This justified critique informs the formulation of this work. Canine olfaction offers a concrete model for testing mechanisms with predefined thresholds of success/failure, affordances for naturalistic testing, and hefty practical and real-world implications. Moreover, the uniqueness of the human-dog relationship allows canine olfaction to be a novel cognitive process that necessarily entails an inter-species extension of cognition, a point whose implications tend to be under-appreciated or even misconstrued in the existing literature. Finally, canine cognition has considerable value from a comparative neuroscience perspective, as their societal enculturation obviates their need for artificially constructed motivation tools such as fluid/food restrictions that tend to limit generalizability, as well as their evolutionary history in the human social environment meaning that they share with us key behavioral and functional characteristics in socio-cognitive skills Bunford et al.. Thus, furthering our understanding of the canine mind will better allow us to understand the complexities of our own.

Before finally diving into the 4E-ness of canine olfaction, it is necessary to briefly present two streams of canine research that will frame our discussion — the canine theory of mind and the degree of human-canine cooperation.

Empirical evidence has gathered to suggest that dogs possess a high level of social cognitive complexity that allows them to make the self-other distinction. While one can't help but be reminded of puppies barking (and cowering) in attempts to intimidate their reflections, Horowitz and co found evidence to support the claim that "dogs distinguish between the olfactory "image" of themselves when modified" as witnessed by them investigating "their own odour for longer when it had an additional odour accompanying it than when it did not", thus displaying a rare level of self-awareness amongst animalia, at least as measured by such variants of the mirror self-reflection task Horowitz [2017]. Canids also seem capable of distinguishing between true and false beliefs in human; in an experimental set-up designed by Lonardo and colleagues Lonardo et al. [2021], dogs followed a human's misleading suggestions less often when they were aware that the informant possessed a true belief versus a false one and hence, appear able to tell truth from lies, suggesting a fairly sophisticated theory of mind.

With their thousands of years of coevolution with humans, it is no surprise that dogs are highly attuned to human cooperation, with the similarity of individual differences in cooperative communication skills between humans and dogs out-surpassing those of humans and chimpanzees MacLean et al. [2017]. Dogs are highly attuned to a human's gaze Téglás et al. [2012], voices Andics et al. and facial expressions Müller et al. [2015] and are notoriously successful in using pointing as a communicative gesture Kaminski and Nitzschner [2013]. These abilities tend to be resistant to being explained away by lower-level theories of mere associativity or conditioning and instead appear to be innate, dynamic and generative. Canids are also able to make inferences about the underlying content of facial emotions as well as display different brain responses to semantic and intonational properties of spoken language as measured by fMRI Müller et al. [2015], Andics et al..

4 Detecting the E in Canine

4.1 Canine Olfaction as Embodied

Arguing that canine olfaction is embodied is making the claim that olfaction is either constituted by or causally dependent on bodily processes outside the brain. By this, we are not making the inane observation that without a nose or four limbs to move towards odors, canines would be unable to perform olfaction. Rather, we are making two less obvious claims - a) bodily factors such as the physical health and condition of the canine causally affect olfactory

performance, i.e. they display weak embodiment, and b) bodily processes such as the microbiome, nostril movement, respiration, and posture are constitutive of olfactory processes, i.e they display strong embodiment. Remember that our definition of a feature being constitutive of a process is if it belongs to a set of features that are minimally sufficient to create the process.

The physical fitness and conditioning of a dog appears to have an effect on her olfactory performance. Altom and co found that dogs who were exposed to a conditioning regime performed significantly better than dogs who were not at an olfaction task post-exercise Altom et al. [2003]. While they speculated that this was because of panting effects, Angle and co found a similar, though not as significant, effect on performance irrespective of trial number - indicating an effect mediated separately from the degree of airflow afforded Angle et al. [2014]. Hunger and satiety have been seen to affect odor detection in rats, with fasting increasing and satiety decreasing odor performance Aimé et al. [2007]. Animal protein, corn oil, EPA, DPA, and DHA supplements all improved olfactory acuity Jenkins et al. [2018].

Much remains unknown about the complex effects between an organism and its resident microbiome. A 4E approach must take into account the complex “ever-evolving circular causal relation” Palacios-García et al. [2022] that takes place between the microbiome and an organism’s cognition. One hypothesis suggested by Jenkins and colleagues is that GI microbiota may affect serotonin secretion and regulation Yano et al. [2015], which has been shown to affect olfactory processing in mice Dugué and Mainen [2009]. Even more pertinently, Koskinen and colleagues Koskinen et al. [2018] found that the composition of nasal microbiota differed significantly in human subjects with impaired, normal, and enhanced olfactory function and postulated that nasal microbiota may shape olfactory perception by emitting certain compounds. Finally, Isaiah and colleagues Isaiah et al. [2017] investigated the oral and nasal microbiota in three classes of detection dogs - explosives, narcotics, and vapor wave – and found a significant albeit small difference between groups in the composition of oral microbiota.

Dogs have been reported to engage in asymmetrical nostril use. As olfactory processing in canines is ipsilateral, i.e. left nostril stimuli is processed by the left hemisphere and the same for the right nostril, asymmetric nostril usage patterns have a significant effect on olfactory perception. Dogs appear to preferentially use their right nostril when sniffing novel stimuli and shift to using their left nostril upon repeated presentation Siniscalchi et al. [2016]. What is more, dogs preferentially used their right nostril in smelling odors from other dogs in stressful situations versus using their left nostril for odors from dogs in neutral situations. This laterality-emotional trend was reversed when dogs were presented with human odors. The study also captured cardiac data using ECG and observed that the presentation of emotional odors significantly affected basal heart rate Siniscalchi et al. [2016].

Finally, it is worth paying attention to the seemingly innocuous and unique final step in canine olfaction - the indication cue to the human handler. Canines need to be trained to indicate their perceived detection of the target odor and are generally made to either sit down or stand and stare upon odor detection. Essler and colleagues investigated the differences in search behavior that the two modalities engendered and found that the number of hesitations differed based on the cue modality, specifically stand-state dogs displayed four times the number of hesitations than sit dogs. Here, hesitations were defined as search durations that were greater than a true pass (where dogs correctly pass over a non-target odor) but where the dog nevertheless did not alert to the odor. Crucially, the authors point out that the stand-stare modality allowed for a greater degree of flexibility by avoiding restricting the communicated signal to a binary sit/not-sit Essler et al. [2020] as well as allowing for a greater degree of time spent close to the odor port.

4.2 Canine Olfaction as Enacted

To claim that canine olfaction is strongly enacted is to say that the sensorimotor patterns generated by the dog smelling a pedestal is constitutive of the dog’s perception of the odors of the pedestal. In other words, if we alter the parameters of the action of smelling, we change the perception of the odor, even if nothing changes about the properties of the odor itself. This claim appears well supported by evidence from studies on sniffing and respiration.

The 2006 paper by Mainland & Sobel Mainland and Sobel [2006] that was briefly mentioned before makes a claim readily interpreted as strong enactivism, “Olfaction typically consists of both sniffing (airflow in the nostril regardless of odor presence) and smelling (the percept of odor regardless of airflow in the nostril). Although olfactory perception is usually assumed to reflect the latter, it is largely dependent on the former.” M&S go on to propose that sniffing alters both the intensity and identity of the olfactory percept. They hypothesize the latter effect on odorant identity to be a function of airflow velocity — higher velocities would facilitate greater perception of higher sorption odorants and lower velocities would facilitate greater perception for lower sorption odorants. Moreover, the two nostrils tend to experience varying changes in blood pressure that make it such that one nostril has a higher airflow velocity than the other, meaning the olfactory percept varies between nostrils. M&S also draw attention to the way sniffs appear capable of generating theta (γ) and gamma (θ) rhythms, independent of the presence of odors. The dynamic coupling of action and perception is also well-evident in the ways sniff airflow and sniff duration are modulated by odorant properties — i)

an inverse relation is seen between sniff airflow and odorant concentration - high concentration odors correlate with higher sniff airflow velocities, ii) an inverse relation is also seen between sniff duration and odorant concentration - low concentration odors correlate with longer sniff durations Mainland and Sobel [2006].

Since the publication of their paper in 2006, further empirical evidence has accrued in support of Mainland and Sobel's hypotheses. Verhagen and colleagues Verhagen et al. [2007] performed experiments with freely exploring rats and found that "Sniff frequency-dependent filtering of sensory input to the olfactory bulb provides a mechanism by which behavioral state can modulate how sensory information is encoded and processed". Experiments in mice found that "mouse sniffing behavior is highly dynamic, varies with behavioral context, and is strongly modulated by olfactory as well as non olfactory events." Wesson et al. [2008].

The vital role of sniffing in determining the odor percept implies that canine sniffing behavior could be predictive of olfactory performance. This is exactly what was found in experiments with 10 working dogs, where dogs spent significantly less time sniffing true negative samples, as compared to true positives, false negatives, and false positives Concha et al. [2014]. This complex relationship between olfaction and sniffing is further complicated by the role of respiration, particularly nasal respiration, in driving cortical oscillations. Nasal respiration appears to entrain the activity of wide-spread brain regions, including but limited to, olfactory regions such as the piriform cortex, and is seen to affect cognitive processes such as memory consolidation and emotional discrimination Zelano et al. [2016], Tort et al. [2018]. Importantly, a primary driver of this respiration entrainment appears to be the rhythm and a recent study indicated that these changes in appear to be the result of functional activity in the brain. However, changes in rhythms appear to be caused by peripheral refference signals. Yet another complex reciprocal coupling appears to exist, although the details are not just out-of-scope for this paper but remain to be understood by the field in general.

4.3 Canine Olfaction as Embedded

Claiming canine olfaction is embedded holds that extracranial processes play a causal role in a cognitive process. This is most clearly illustrated in canine olfaction in the 'wild'.

In the wild, olfaction takes place in a highly dynamic environment where fluctuations in meteorological variables can have a huge impact on the structure of odor plumes and the chemical composition of odor reservoirs. Three especially important environmental variables are the relative humidity, air temperature and wind speed. In a 2020 study on the strategies employed by trained search and rescue dogs in the field, Jinn and colleagues found that search dogs maintained a high level of success by adjusting their search strategies contingent on meteorological conditions. In conditions of high heat and low humidity, dogs utilized slower search strategies focused on ground-based odor sampling, whereas in lower heat and higher humidity, dogs utilized air-based odor sampling strategies. Dogs were also seen to use ground-sampling when they wandered too far from the trail or when they needed to return to the target odor, leveraging the fact that air near the ground likely contains odors at a higher concentration Jinn et al. [2020].

Intriguingly, researchers in India found a significantly strong association between monsoon seasons and mating patterns in free-ranging dogs. Since such an association cannot be explained by ecological reasons like a whelping resource abundance hypothesis, the researchers argued that the increased humidity during the monsoon aided the dispersal and perception of pheromones, which allowed male dogs to identify and locate female dogs in heat Sen Majumder S..

4.4 Canine Olfaction as Extended

"Species interdependence is the name of the worlding game on earth, and that game must be one of response and respect. That is the play of companion species learning to pay attention. Not much is excluded from the needed play, not technologies, commerce, organisms, landscapes, peoples, practices. I am not a posthumanist; I am who I become with companion species, who and which make a mess out of categories in the making of kin and kind. Queer messmates in mortal play, indeed." Donna Haraway, *When Species Meet* Haraway [2008]

We have finally arrived at our last E and this is where matters get extendedly interesting. Initially, one can wonder at how canine olfaction can be construed of as extended, for canines do not typically use tools - the prototypical example of extended cognition that forms the cornerstone of Clark and Chalmers' eponymous essay.

However, upon further thought, it is readily apparent that canine olfaction extends outwards into us - their sapien counterparts. Dogs smell through humans and humans smell through dogs, we are enfolded in a "mutual entrainment ... whereby the dynamics of interaction form an extended body" Froese [2014].

As Haraway has eloquently argued, humans and wolves domesticated each other throughout our co-evolving history - what Tom Froese calls a "social co-determination" - and this history of our extended body's "dynamical entanglement" continues through the "inter-bodily resonance between individuals" and gives "rise to self-sustaining interaction

patterns that go beyond the behavioral capacities of isolated individuals by modulating their intra-bodily conditions of behavior generation.” Froese and Fuchs [2012]. A dog cannot smell a malignant tumor without sustained and repeated cooperation that is centered around a bond of trust and understanding with her human guardian.

Like everything we have been discussing, this insight has real-world practical implications. In a 2011 study, Lit and colleagues tested the effect of imparting false beliefs in handlers on detection dyad performance. False beliefs in handlers generated a large number of false alerts, with false alerts to handler decoys being higher than false alerts to canine decoys Lit et al. [2011]. A follow-up study by DeChant and colleagues did not replicate this result but did find that handler knowledge of testing parameters influenced the search behavior adopted by the dyad team DeChant et al. [2020].

Further evidence of the importance of the human-canine relationship in canine olfactory performance comes from studies seeking to extract relevant cognitive measures that can select better performing working dogs. In a series of studies, MacLean and Hare found that the strongest predictors of a detection dog’s performance were individual differences in ‘sensitivity to human gestural communication’ and short-term memory MacLean and Hare [2018]. In the same vein, a criterion analysis of qualitative handler reports suggested that the behavioral trait of ‘playfulness’ was important in assessing the performance of a detector dog Rocznik et al. [2015]. Why would playfulness be important to the detection of odors? This odd piece of evidence makes sense when we consider the cognitive eccentricity of play — what Michele Merritt describes as “sympoetic enactivism” Merritt [2021]. Merritt describes play as generating intersubjective cognition where new ways of thinking and relating are created. As such, the success of an operationalized trait of ‘playfulness’ in predicting detection performance could be pointing towards the importance of this intersubjective cognition in canine olfaction, in other words, implying its extended nature.

An important mechanism that may underlie this feature of the canine-human relationship is the oxytocin-gaze positive human-canine loop. Japanese researchers found that spraying dogs with oxytocin promoted positive social behaviours to other dogs as well as human partners Romero et al. [2014]. In a follow-up study published in *Science* in 2015, the researchers found the existence of a fascinating positive loop, where dogs gazing at their human partners increased human oxytocin levels, which caused an increase in human-lead interactions with the dogs, that subsequently increased canine oxytocin levels Nagasawa et al. [2015]. Finally, the same researchers examined the genotype of 340 Labradors and found that a certain canine oxytocin receptor (OXTR) allele was significantly correlated with success at a drug detection training program Konno et al. [2018].

Finally, it is intriguing to marvel at the intriguing albeit obvious-in-hindsight discovery that adults cohabiting with dogs displayed a greater degree of shared microbiota with their furry companions than with dogs they did not live with. The effects of this literal sharing of embodiment on the socio-cognitive bond can only be speculated Song et al. [2013].

5 Barks and Bytes

“...without the proper technological advances the road ahead is blocked. Without a guiding vision there is no road ahead” Carl Woese, *A new biology for a new century* Woese [2004]

In an influential article in *Neuron*, Krakauer and colleagues push for a correction to the prevalent reductionist bias they see enveloping the neurosciences by emphasizing the importance of behavior in providing scientific understanding. Their argument hinges on the particular definition of the concept of a ‘mechanism’, which they borrow from Bechtel as “a structure performing a function in virtue of its component parts, component operations, and their organization. The orchestrated functioning of the mechanism is responsible for one or more phenomena” Bechtel [2007]. Isolating neural components from a cognitive process erases the emergence that occurs when those components work in concert. That is, “Ion channels do not beat, heart cells do. Neural circuits do not feel pain, whole organisms do.” Krakauer et al. [2017].

This sentiment is much needed in a reductionist era, but it doesn’t go far enough. For in the same vein that it is the whole organism who feels pain, not just a neural circuit, it is the whole canine-human-environment unit that performs olfaction, not just the brain. Cognitive (neuro)science doesn’t just need behavior, it needs the entire gamut of dynamic interactions in order to provide sufficiently informed models that can take into account the embodied-enacted-embedded-extended nature of cognition. Fortunately, the cognitive scientist in the 21st century is well-equipped to run this gamut. Indeed, one could say now is the perfect time to do so Parada and Rossi [2021].

Body:

In 2014, Bozkurt and colleagues Bozkurt et al. [2014] published an article titled *Towards Cyber-Enhanced Working Dogs for Search and Rescue*, wherein they proposed a ‘cyber-enabled, computer-mediated communication platform to connect canine and human intelligences’. The hypothetical platform was housed in a canine vest and consisted of a sensor set - camera, microphone, GPS, IMUs, ECG and PPG - that would capture video, audio, location, movement and

posture, heart-rate, and respiration data respectively. (Bozkurt et al., 2014) Since then, members from the team claim to have successfully created prototypes of a wearable canine ECG Brugarolas et al. [2016]), as well as an electronic stethoscope that captures respiratory data and accurately categorizes sniffing events Brugarolas et al. [2019].

Environment:

Experiments with mice using virtual reality have been performed since 2009 Harvey et al. [2009], with an olfactory virtual reality paradigm deployed in 2019 Radvansky and Dombeck [2018]. In 2020, the BBC reported that the US Army had acquired augmented reality goggles for their military dogs ('US Army Trials Augmented Reality Goggles for Dogs', 2020).

Brain:

Portable neuroimaging techniques have been deployed to measure the brain activity of animals, with advances in spatial and temporal resolution likely to accelerate given surging interest in human neuro-wearables. Primitive models of functional near-infrared spectroscopy (fNIRS) have been used to collect data from dogs during human interactions Gygax et al. [2015]. More recently, a sophisticated fNIRS set-up was used to measure brain activity caused by movement in sheep Chincari et al.. Finally, multi-channel EEG in stationary dogs was used to reveal temporal features in face processing Kujala et al. [2020].

Taken together, these technological tools can be used to collect/construct holistic data from the brain, body, and environment during naturalistic olfactory task conditions. Machine learning models can then map the dynamic web of interactions and synchronizations across domains leading to rich 4E insight into the nature of canine olfaction.

6 Conclusion

We live in an unprecedented time of viral-induced-anosmia and an emerging epidemic of Covid-dementia. Even mild Covid cases are being observed to lead to significant cognitive dysfunction Hampshire et al. [2021], Douaud et al. [2022]. Significantly, cognitive dysfunction and Long Covid symptomatology seems to correlate with degree of anosmia. It appears that we need to re-think our understanding of olfaction in relation to human health and well-being.

At the same time, we exist in an exciting time of technological advancement. Both our ability to acquire and analyze data has increased dramatically in the past few decades. Yet, our efforts seem to be directed towards the further extraction of resources — from plundering the Earth to plundering our collective attention — our notion of technology is entombed in what Heidegger would call a 'challenging', where objects are qualified by their degree of 'standing-reserve'. However, an alternate mode of technology exists, what Heidegger calls 'poiesis', that can be understood as an unconcealment or bringing-forth of the true nature of things Heidegger [1977].

By combining the theoretical richness and wideness of 4E, the technological prowess of the current moment, and our intergenerational bond with our canine comrades, we must just be able to finally crack the olfactory 'code' and in the process, reveal the essence of cognition itself.

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