Animal Abduction

From Mindless Organisms to Artifactual Mediators

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Summary. Many animals – traditionally considered "mindless" organisms – make up a series of signs and are engaged in making, manifesting or reacting to a series of signs: through this semiotic activity – which is fundamentally *model-based* – they are at the same time engaged in "being cognitive agents" and therefore in thinking intelligently. An important effect of this semiotic activity is a continuous process of "hypothesis generation" that can be seen at the level of both instinctual behavior, as a kind of "wired" cognition, and representation-oriented behavior, where nonlinguistic pseudothoughts drive a plastic model-based cognitive role. This activity is at the root of a variety of *abductive* performances, which are also analyzed in the light of the concept of affordance. Another important character of the model-based cognitive activity above is the externalization of artifacts that play the role of mediators in animal languageless reflexive thinking. The interplay between internal and external representation exhibits a new cognitive perspective on the mechanisms underlying the semiotic emergence of abductive processes in important areas of model-based thinking of mindless organisms. To illustrate this process I will take advantage of the case of affect attunement which exhibits an impressive case of model-based communication. A considerable part of abductive cognition occurs through an activity consisting in a kind of reification in the external environment and a subsequent re-projection and reinterpretation through new configurations of neural networks and of their chemical processes. Analysis of the central problems of abduction and hypothesis generation helps to address the problems of other related topics in model-based reasoning, like pseudological and reflexive thinking, the role of pseudoexplanatory guesses in plastic cognition, the role of reification and beliefs, the problem of the relationship between abduction and perception, and of rationality and instincts.

1 Mindless Organisms and Cognition

Philosophy has for a long time disregarded the ways of thinking and knowing of animals, traditionally considered "mindless" organisms. Peircean insight regarding the role of abduction in animals was a good starting point, but

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only more recent results in the fields of cognitive science and ethology about animals, and of developmental psychology and cognitive archeology about humans and infants, have provided the actual intellectual awareness of the importance of the comparative studies.

Philosophy has anthropocentrically condemned itself to partial results when reflecting upon human cognition because it lacked in appreciation of the more "animal-like" aspects of thinking and feeling, which are certainly in operation and are greatly important in human behavior. Also in ethical inquiry a better understanding of animal cognition could in turn increase knowledge about some hidden aspects of human behavior, which I think still evade any ethical account and awareness.

In the recent [1] I maintain that people have to learn to be "respected as things", sometimes, are. Various kinds of "things", and among them work of arts, institutions, symbols, and of course animals, are now endowed with intrinsic moral worth. Animals are certainly morally respected in many ways in our technological societies, but certain knowledge about them has been disregarded. It is still difficult to acknowledge respect for their cognitive skills and endowments. Would our having more knowledge about animals happen to coincide with having more knowledge about humans and infants, and be linked to the suppression of constitutive "anthropomorphism" in treating and studying them that we have inherited through tradition? Consequently, would not novel and unexpected achievements in this field be a fresh chance to grant new "values" to humans and discover new knowledge regarding their cognitive features? [2] Darwin has already noted that studying cognitive capacities in humans and non-humans animals "[...] possesses, also, some independent interest, as an attempt to see how far the study of the lower animals throws light on one of the highest psychical faculties of man" – the moral sense [3].

Among scientists it is of course Darwin [4] who first clearly captured the idea of an "inner life" (the "world of perception" included) in some humble earthworms [5]. A kind of mental life can be hypothesized in many organisms: Darwin wanted "to learn how far the worms acted consciously and how much mental power they displayed" [4, p. 3]. He found levels of "mind" where it was not presumed to exist. It can be said that this new idea, which bridges the gap between humans and other animals, in some sense furnishes a scientific support to that metaphysical synechism claimed by Peirce contending that matter and mind are intertwined and in some sense indistinguishable[1].

1.1 Worm Intelligence, Abductive Chickens, Instincts

Let us consider the behavior of very simple creatures. Earthworms plug the opening of their burrow with leaves and petioles: Darwin recognized that

[1] The recent discovery of the cognitive roles (basically in the case of learning and memory) played by spinal cord further supports this conviction that mind is extended and distributed and that it can also be – so to say – "brainless" [6].

behavior as being too regular to be random and at the same time too variable to be merely instinctive. He concluded that, even if the worms were innately inclined to construct protective basket structures, they also had a capacity to "judge" based on their tactile sense and showed "some degree of intelligence" [4, p. 91]. Instinct alone would not explain how worms actually handle leaves to be put into the burrow. This behavior seemed more similar to their "having acquired the habit" [4, p. 68]. Crist says: "Darwin realized that 'worm intelligence' would be an oxymoron for skeptics and even from a commonsense viewpoint 'This will strike everyone as very improbable' he wrote [4, p. 98]. [...] He noted that little is known about the nervous system of 'lower animals', implying they might possess more cognitive potential than generally assumed" [5, p. 5].

It is important to note that Darwin also paid great attention to those external structures built by worms and engineered for utility, comfort, and security. I will describe later on in this article the cognitive role of artifacts in both human and non-human animals: artifacts can be illustrated as *cognitive mediators* [7] which are the building blocks that bring into existence what it is now called a "cognitive niche"[2]. Darwin maintains that "We thus see that burrows are not mere excavations, but may rather be compared with tunnels lined with cement" [4, p. 112]. Like humans, worms build external artifacts endowed with precise roles and functions, which strongly affect their lives in various ways, and of course their opportunity to "know" the environment.

I have said their behavior cannot be accounted for in merely instinctual terms. Indeed, the "variability" of their behavior is for example illustrated by the precautionary capacity of worms to exploit pine needles by bending over pointed ends: "Had this not effectually been done, the sharp points could have prevented the retreat of the worms into their burrows; and these structures would have resembled traps armed with converging points of wire rendering the ingress of an animal easy and its egress difficult or impossible" [4, p. 112]. Cognitive *plasticity* is clearly demonstrated by the fact that Darwin detected that pine was not a native tree! If we cannot say that worms are aware like we are (consciousness is unlikely even among vertebrates), certainly we can acknowledge in this case a form of material, interactive, and embodied, manifestation of awareness in the world.

Recent research has also demonstrated the existence of developmental plasticity in plants [11]. For example developing tissues and organs "inform" the plant about their states and respond according to the signals and substrates they receive. The plant adjusts structurally and physiologically to its own development and to the habitat it happens to be in (for example a plasticity of organs in the relations between neighboring plants can be developed) [12, 13].

In this article I am interested in improving knowledge on abduction and model-based thinking. By way of introduction let me quote the interesting

[2] A concept introduced by Tooby and DeVore [8] and later on reused by Pinker [9, 10].

Peircean passage about hypothesis selection and chickens, which touches on both ideas, showing a kind of completely language-free, model-based abduction:

> How was it that man was ever led to entertain that true theory? You cannot say that it happened by chance, because the possible theories, if not strictly innumerable, at any rate exceed a trillion – or the third power of a million; and therefore the chances are too overwhelmingly against the single true theory in the twenty or thirty thousand years during which man has been a thinking animal, ever having come into any man's head. Besides, you cannot seriously think that every little chicken, that is hatched, has to rummage through all possible theories until it lights upon the good idea of picking up something and eating it. On the contrary, you think the chicken has an innate idea of doing this; that is to say, that it can think of this, but has no faculty of thinking anything else. The chicken you say pecks by instinct. But if you are going to think every poor chicken endowed with an innate tendency toward a positive truth, why should you think that to man alone this gift is denied? [14, 5.591]

and again, even more clearly, in another related passage

> When a chicken first emerges from the shell, it does not try fifty random ways of appeasing its hunger, but within five minutes is picking up food, choosing as it picks, and picking what it aims to pick. That is not reasoning, because it is not done deliberately; but in every respect but that, it is just like abductive inference[3].

From this Peircean perspective hypothesis generation is a largely instinctual and *nonlinguistic* endowment of human beings and, of course, also of animals. It is clear that for Peirce abduction is rooted in the instinct and that many basically instinctual-rooted cognitive performances, like emotions, provide examples of abduction available to both human and non-human animals. Also cognitive archeology [16, 17] acknowledges that it was not language that made cognition possible: rather it rendered possible the integration in social environments of preexistent, separated, domain-specific modules in prelinguistic hominids, like complex motor skills learnt by imitation or created independently for the first time [18]. This integration made the emergence of tool making possible through the process of "disembodiment of mind" that I recently illustrated in [19]. Integration also seeks out established policies, rituals, and complicated forms of social cognition, which are related to the other forms of prevalently nonlinguistic cognitive behaviors.

[3] Cf. the article "The proper treatment of hypotheses: a preliminary chapter, toward and examination of Hume's argument against miracles, in its logic and in its history" (1901) [15, p. 692].

1.2 Nonlinguistic Representational States

It can be hypothesized that some language-free, more or less stable, *representational* states that are merely model-based[4] are present in animals, early hominids, and human infants. Of course tropistic and classically conditioned schemes can be accounted for without reference to these kind of model-based "representations", because in these cases the response is invariant once the creature in question has registered the relevant stimuli.

The problem of attributing to those beings strictly nonlinguistic model-based inner "thoughts", beliefs, and desires, and thus suitable ways of representing the world, and of comparing them to language-oriented mixed (both model-based and sentential) representations, typical of modern adult humans, appears to be fundamental to comprehending the status of animal presumptive abductive performances.

Of course this issue recalls the traditional epistemological Kuhnian question of the incommensurability of meaning [21]. In this case it refers to the possibility of comparing cognitive attitudes in different biological species, which express potentially incomparable meanings. Such problems already arose when dealing with the interpretation of primitive culture. If we admit, together with some ethologists, animal behaviorists, and developmental psychologists, that in nonlinguistic organisms there are some intermediate representations, it is still difficult to make an analogy with those found in adult humans. The anthropologists who carried out the first structured research on human primitive cultures and languages already stressed this point, because it is difficult to circumstantiate thoughts that can hold in beings but only manifest themselves in superficial and external conducts (cf. Quine [22]).

A similar puzzling incommensurability already arises when we deal with the different sensorial modalities of certain species and their ways of being and of feeling to be in the world. We cannot put ourselves in the living situation of a dolphin, which lives and feels by using echolocations, or of our cat, which "sees" differently, and it is difficult to put forward scientific hypotheses on these features using human-biased language, perceptive capacities, and cognitive representations. The problem of the existence of "representation states" is deeply epistemological: the analogous situation in science concerns for example the status of the so-called theoretical terms, like quarks or electrons, which are not directly observable but still "real", reliable, and consistent when meaningfully legitimated/justified by their epistemological unavoidability in suitable scientific research programs [23].

I have already said that commitment to research on animal cognition is rare in human beings. Unfortunately, even when interested in animal

[4] They do not have to be taken like for example visual and spatial imagery or other internal model-based states typical of modern adult humans, but more like action-related representations and thus intrinsically intertwined with perception and kinesthetic abilities. Saidel [20] interestingly studies the role of these kinds of representations in rats.

cognition, human adult researchers, victims of an uncontrolled, "biocentric" anthropomorphic attitude, always risk attributing to animals (and of course infants) our own concepts and thus misunderstanding their specific cognitive skills [24].

2 Animal Abduction

2.1 "Wired Cognition" and Pseudothoughts

Nature writes programs for cognitive behavior in many ways. In certain cases these programs draw on cognitive functions and sometimes they do not. In the latter case the fact that we describe the behavioral effect as "cognitive" is just a metaphor. This is a case of *instinctual* behavior, which we should more properly name "wired cognition".

Peirce spoke – already over a century ago – of a wide semiotic perspective, which taught us that a human internal representational medium is not necessarily structured like a language. In this article I plan to develop and broaden this perspective. Of course this conviction strongly diverges from that maintained by the intellectual traditions which resort to the insight provided by the modern Fregean logical perspective, in which thoughts are just considered the "senses of sentences". Recent views on cognition are still influenced by this narrow logical perspective, and further stress the importance of an isomorphism between thoughts and language sentences (cf. for example Fodor's theory [25]).

Bermúdez clearly explains how this perspective also affected the so-called *minimalist view* on animal cognition (also called *deflationary view*) [18, p. 27]. We can describe nonlinguistic creatures as thinkers and capable of goal-directed actions, but we need to avoid assigning to them the type of thinking common to linguistic creatures, for example in terms of belief-desire psychology: "Nonlinguistic thinking does not involve propositional attitudes – and, a fortiori, psychological explanation at the nonlinguistic level is not a variant of belief-desire psychology" (*ibid.*). Belief-desire framework should only be related to linguistic creatures. Instead, the problem for the researcher on animal cognition would be to detect how a kind of what we can call "general belief" is formed, rather than concentrating on its content, as we would in the light of human linguistic tools.

Many forms of thinking, such as imagistic, empathetic, trial and error, and analogical reasoning, and cognitive activities performed through complex bodily skills, appear to be basically model-based and manipulative. They are usually described in terms of living beings that adjust themselves to the environment rather than in terms of beings that acquire information from the environment. In this sense these kinds of thinking would produce responses that do not seem to involve sentential aspects but rather merely "non-inferential" ways of cognition. If we adopt the semiotic perspective above, which does not reduce the term "inference" to its sentential level, but which includes the whole arena of sign activity – in the light of Peircean tradition – these kinds of thinking promptly appear full, inferential forms of thought. Let me recall that Peirce stated that all thinking is in signs, and signs can be icons, indices, or symbols, and, moreover, all *inference* is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" [14, 5.283].

From this perspective human and the most part of non-human animals possess what I have called *semiotic brains* [26], which make up a series of signs and which are engaged in making or manifesting or reacting to a series of signs: through this semiotic activity they are at the same time occasionally engaged in "being cognitive agents" (like in the case of human beings) or at least in thinking intelligently. For example, spatial imaging and analogies based on perceiving similarities – fundamentally context-dependent and circumstantiated – are ways of thinking in which the "sign activity" is of a nonlinguistic sort, and it is founded on various kinds of implicit naïve physical, biological, psychological, social, etc., forms of intelligibility. In scientific experimentation on prelinguistic infants a common result is the detection of completely language-free working ontologies, which only later on, during cognitive development, will become intertwined with the effect of language and other "symbolic" ways of thinking.

With the aim of describing the kinds of representations which would be at work in these nonlinguistic cognitive processes Dummett [27] proposes the term *protothought*. I would prefer to use the term *pseudothought*, to minimize the hierarchical effect that – ethnocentrically – already affected some aspects of the seminal work on primitives of an author like Lévi-Bruhl [28]. An example of the function of model-based pseudothoughts can be hypothesized in the perception of space in the case of both human and non-human animals. The perceived space is not necessarily three-dimensional and merely involves the apprehension of movement changes, and the rough properties of material objects. Dummett illustrates the case of the car driver and of the canoeist:

> A car driver or canoeist may have to estimate the speed and direction of oncoming cars and boats and their probable trajectory, consider what avoiding action to take, and so on: it is natural to say that he is highly concentrated in thought. But the vehicle of such thoughts is certainly not language: it would be said, I think, to consist in visual imagination superimposed on the visual perceived scene. It is not just that these thoughts are not in fact framed in words: it is that they do not have the structure of verbally expressed thoughts. But they deserve the name of "protothoughts" because while it would be ponderous to speak of truth or falsity in application to them, they are intrinsically connected with the possibility of their being mistaken: judgment, in a non-technical sense, is just what the driver and the canoeist need to exercise. [27, p. 122]

2.2 Plastic Cognition in Organisms' Pseudoexplanatory Guesses

To better understand what the study of nonlinguistic creatures teaches us about model-based and manipulative abduction (and go beyond Peirce's insights on chickens' "wired" abductive abilities), it is necessary to acknowledge the fact that it is difficult to attribute many of their thinking performances to innate releasing processes, trial and error or to a mere reinforcement learning, which do not involve complicated and more stable internal representations.

Fleeting and evanescent (not merely reflex-based) pseudorepresentations are needed to account for many animal "communication" performances even at the level of the calls of "the humble and much-maligned chicken", like Evans says:

> We conclude that chicken calls produce effects by evoking representations of a class of eliciting events [food, predators, and presence of the appropriate receiver]. This finding should contribute to resolution of the debate about the meaning of referential signals. We can now confidently reject reflexive models, those that postulate only behavioral referents, and those that view referential signals as imperative. The humble and much maligned chicken thus has a remarkably sophisticated system. Its calls denote at least three classes of external objects. They are not involuntary exclamations, but are produced under particular social circumstances. [29, p. 321]

In sum, in nonlinguistics animals, a higher degree of *abductive* abilities has to be acknowledged: chicken form separate representations faced with different events and they are affected by prior experience (of food, for example). They are mainly due to internally developed plastic capacities to react to the environment, and can be thought of as the fruit of learning. In general this plasticity is often accompanied by the suitable reification of external artificial "pseudorepresentations" (for example landmarks, alarm calls, urinemarks and roars, etc.) which artificially modify the environment, and/or by the referral to externalities already endowed with delegated cognitive values, made by the animals themselves or provided by humans.

The following is an example of not merely reflex-based cognition and it is fruit of plasticity: a mouse in a research lab perceives not simply the lever but the fact that the action on it affords the chance of having food; the mouse "desires" the goal (food) and consequently acts in the appropriate way. This is not the fruit of innate and instinctual mechanisms, merely a trial and error routine, or brute reinforcement learning able to provide the correct (and direct) abductive appraisal of the given environmental situation. Instead it can be better described as the fruit of learnt and flexible thinking devices, which are not merely fixed and stimulus driven but also involve "thought". "Pseudothought" – I have already said – is a better term to use, resorting to the formation of internal structured representations and various – possibly new – links between them. The mouse also takes advantage in its environment of an external device, the lever, which the humans have endowed with a fundamental predominant cognitive value, which can afford the animal: the mouse is able to cognitively pick up this externality, and to embody it in internal, useful representations.

Another example of plastic cognition comes from the animal activity of reshaping the environment through its mapping by means of seed caches:

> Consider, for example, a bird returning to a stored cache of seeds. It is known from both ethological studies and laboratory experiments that species such as chickadees and marsh tits are capable of hiding extraordinary number of seeds in a range of different hiding places and then retrieving them after considerable periods of time have elapsed. ([30], quoted in [18, p. 48])

It is also likely to hypothesize that this behavior is governed by the combination of a motivational state (a general desire for food) and a memory of the particular location, and how to get to it[5]. The possibility of performing such behavior is based on structured internal pseudorepresentations originating from the previous interplay between internal and external signs suitably picked up from the environment in a step-by-step procedure.

To summarize, in these cases we are no longer observing the simple situation of the Peircean, picking chicken, which "[...] has an innate idea of doing this; that is to say, that it can think of this, but has no faculty of thinking anything else". This "cognitive" behavior is the one already described by the minimalist contention that there is no need to specify any kind of internal content. It is minimally – here and now and immediately related to action – goal-directed, mechanistic, and not "psychological" in any sense, even in a metaphorical one, as we use the term in the case of animals [18, p. 49].

On the contrary, the birds in the example above have at their disposal flexible ways of reacting to events and evidence, which are explainable only in terms of a kind of *thinking* "something else", to use the Peircean words, beyond mere mechanistic pre-wired responses. They can choose between alternative behaviors founding their choice on the basis of evidence available to be picked up. The activity is "abductive" in itself: it can be *selective*, when the pseudoexplanatory guess, on which the subsequent action is based, is selected among those already internally available, but it can also be *creative*, because the animal can form and excogitate for the first time a particular pseudo-explanation of the situation at hand and then creatively act on the basis of it. The tamarins quickly learn to select the best hypothesis about the tool – taking into account the different tools on offer – that has to be used to obtain the most food in "varied" situations. To avoid "psychological" descriptions, animal abductive cognitive reaction at this level can be seen as an emergent property of the whole organism, and not, in an anthropocentric way, as a

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[5] Of course the use of concepts like "desire", deriving from the "folk-psychology" lexicon, has to be considered merely metaphorical.

small set of specialized skills like we usually see them in the case of humans. By the way, if we adopt this perspective it is also easier to think that some organisms can learn and memorize even without the brain[6].

As I will illustrate in subsection 2.4, animals occupy different environmental niches that "directly" afford their possibility to act, like Gibson's original theory teaches, but this is only one of the ways the organism exploits its surroundings to be suitably attuned to the environment. When behaviors are more complicated other factors are at stake. For example, animals can act on a goal that they cannot perceive – the predator that waits for the prey for example – so the organism's appraisal of the situation includes factors that cannot be immediately perceived,

Well-known dishabituation experiments have shown how infants use model-based high-level physical principles to relate to the environment. They look longer at the facts that they find surprising, showing what expectations they have; animals like dolphins respond to structured complex gestural signs in ways that can hardly be accounted for in terms of the Gibsonian original notion of immediate affordance. A similar situation can be seen in the case of monkeys that perform complicated technical manipulations of objects, and in birds that build artifacts to house beings that have not yet been born. The problem here is that organisms can dynamically abductively "extract" or "create" – and further stabilize – affordances not previously available, taking advantage not only of their instinctual capacities but also of the plastic cognitive ones (cf. below subsection 2.4)[7].

2.3 Artifacts and Classical and Instrumental Conditioning

Other evidence supports the assumption about the relevance of nonlinguistic model-based thinking beyond the mere reflex-based level. The birth of what is called material culture in hominids, I will quote in the following subsection, and the use of artifacts as external cognitive mediators in animals, reflect a kind of *instrumental* thought that cannot be expressed in terms of the minimalist conception. The instrumental properties are framed by exploiting artificially made material cognitive tools that *mediate* and so enhance perception, body kinesthetic skills, and a full-range of new cognitive opportunities. Through artifacts more courses of action can be selected, where – so to say – "sensitivity" to the consequences is higher. In this case actions cannot be accounted for solely in terms of the mere perceptual level[8].

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[6] It is interesting to note that recent neurobiological research has shown that neural systems within the spinal cord in rats are quite a bit smarter than most researchers have assumed, they can, for example, learn from experience [6]. Cf. also footnote 1 above.

[7] On the creation/extraction of new affordances through both evolutionary changes and construction of new knowledge and artifacts cf. [31].

[8] This sensitivity is already present in birds like ravens [32].

The difference has to be acknowledged between sensitivity to consequences, which is merely due to innate mechanisms and/or classical conditioning (where behavior is simply modified in an adaptive way on the basis of failures and successes), and the more sophisticated sensitivity performed through some doxastic/representational intermediate states:

> In classical conditioning, a neutral stimulus (e.g., the sound of a bell) is followed by an unconditioned stimulus (e.g., the presentation of food) that elicits a reaction (e.g., salivation). The outcome of classical conditioning is that the conditioned response (the salivation) comes to be given to the conditioned stimulus (the sound of the bell) in the absence of the unconditioned stimulus. In instrumental operant conditioning the presentation of the reinforcing stimulus is contingent on the animal making a particular behavioral response (such as a pecking lever). If the behavioral response does not occur, the reinforcing stimulus is withheld. Classical conditioning behavior is not outcome-sensitive in any interesting sense, since it is not the behavior that is reinforced. [18, p. 167]

It is evident that instrumental conditioning is also important in (and intertwined with) tool and artifact construction where for example the ability to *plan* ahead (modifying plans and reacting to contingencies, such as unexpected flaws in the material and miss-hits) is central.

2.4 Affordances and Abduction

Gibson's eco-cognitive concept of "affordance" [33] and Brunswik's interplay between proximal and distal environment [34] also deal with the problem of the so-called model-based pseudothoughts, which concern any kind of thinking far from the cognitive features granted by human language[9]. These kinds of cognitive tools typical of infants and of many animals (and still operating in human adults in various forms of more or less unexpressed thinking) are hypothesized to express the organic beings' implicit skills to act in a perceived environment as a distal environment ordered in terms of the possibilities to *afford* the action in response to local changes.

Different actions will be suitable to different ways of apprehending aspects of the external world. The objectification of the world made possible by language and other highly abstract organizing cognitive techniques (like mathematics) is not needed. An affordance is a resource or chance that the environment presents to the "specific" organism, such as the availability of water or of finding recovery and concealment. Of course the same part of the environment offers different affordances to different organisms. The concept can be also extended to artificial environments built by humans, my cat affords

[9] A detailed illustration of the relationships between affordances and abduction is given in [31].

her actions in the kitchen of my house differently than me, for example I do not find affordable to easily jump through the window or on the table! I simply cannot imagine the number of things that my cat Sheena is possibly "aware" of (and her way of being aware) in a precise moment, such as the taste of the last mouse she caught and the type of memory she has of her last encounter with a lizard[10]: "Only a small part of the network within which mouseness is nested for us extends into the cat's world" [37, p. 203].

It can be hypothesized that in many organisms the perceptual world is the only possible model of itself and in this case they can be accounted for in terms of a merely reflex-based notions: no other internal more or less stable representations are available. In the case of affordance sensitive organisms described above the coupling with the environment is more flexible because it is important in coupling with the niche to determine what environmental dynamics are currently the most relevant, among the several ones that afford and that are available. An individual that is looking for its prey and at the same time for a mate (which both immediately afford it without any ambiguity) is contemporarily in front of two different affordances and has to *abductively* select the most suitable one weighting them. Both affordances and the more or less plastic processes of their selection in specific situations can be stabilized, but both can also be modified, increased, and substituted with new ones. In animals, still at the higher level on not-merely reflex-based cognitive abilities, no representational internal states need be hypothesized [38].

The etheromorphism of affordances is also important: bats use echolocation, and have a kind of sensory capacity that exceeds that of any man-made systems; dolphins can for example detect, dig out, and feed on fish and small eels buried up to 45 cm beneath the sandy seabed and are able to detect the size, structure, shape, and material composition of distant objects. They can also discriminate among aluminum, copper, and brass circular targets, and among circles, squares, and triangular targets covered with neoprene [39]. These amazing cognitive performances in dolphins are processed through complex computations that transform one dimensional waves (and multiple echoes), arriving at each of their two ears, into representations of objects and their features in the organism's niche. The process is "multimodal" because dolphins also interface with their world using visual and other auditory signals, vocal and behavioral mimicry, and representational capabilities. It even seems that significant degrees of self-awareness are at work, unique to nonhuman

[10] The point of view of Gibson has been taken into account by several people in the computational community, for example by Brooks in robotics [35]. "Vision is not delivering a high level representation of the world, instead it cooperates with motor controls enabling survival behavior in the environment. [...] While it is very sensible that the main goal of vision in humans is to contribute to moving and acting with objects in the word, it is highly improbable that a set of actions can be identified as the output of vision. Otherwise, vision must include all sort of computations contributing to the acting behavior in that set: it is like saying that vision should cover more or less the whole brain activity" [36, pp. 369–370].

animals [40]. It is easy to imagine that we can afford the world in a similar way only by hybridizing ourselves using artificial instruments and tools like sonar: the fruit of modern scientific knowledge.

It is important to note that recent research based on Schrödinger's focusing on energy, matter and thermodynamic imbalances provided by the environment, draws the attention to the fact that all organisms, including bacteria, are able to perform elementary *cognitive functions* because they "sense" the environment and process internal information for "thriving on latent information embedded in the complexity of their environment" (Ben Jacob, Shapira, and Tauber [41, p. 496]). Indeed Schrödinger maintained that life requires the consumption of negative entropy, i.e. the use of thermodynamic imbalances in the environment. As a member of a complex superorganism – the colony, a multi-cellular community – each bacterium possesses the ability to sense and communicate with the other units comprising the collective and performs its work within a distribution task so, bacterial communication entails collective sensing and cooperativity through interpretation of chemical messages, distinction between internal and external information, and a sort of self vs. non-self distinction (peers and cheaters are both active).

In this perspective "biotic machines" are *meaning*-based forms of intelligence to be contrasted with the *information*-based forms of artificial intelligence: biotic machines generate new information, assigning contextual meaning to gathered information: self-organizing organisms like bacteria are afforded – through a real cognitive act – and by "relevant" information that they subsequently couple with the regulating, restructuring, and *plastic* activity of the contextual information (intrinsic meaning) already internally stored, which reflects the intra-cellular state of the cells. Of course the "meaning production" involved in the processes above refers to structural aspects of communication that cannot be related to the specific sentential and model-based cognitive skills of humans, primates, and other simpler animals, but still shares basic functions with these like sensing, information processing, and collective abductive contextual production of meaning. As stressed by Ben Jacob, Shapira, and Tauber

> In short, bacteria continuously sense their milieu and store the relevant information and thus exhibit "cognition" by their ability to process information and responding accordingly. From those fundamental sensing faculties, bacterial information processing has evolved communication capabilities that allow the creation of cooperative structures among individuals to form super-organisms [41, p. 504].

Organisms need to become *attuned* to the relevant features offered in their environment and many of the cognitive tools built to reach this target are the result of evolution. The wired and embodied perceptual capacities and imagistic, empathetic, trial and error, and analogical devices I have described above already fulfill this task. These capabilities can be seen as devices adopted by organisms that provide them with potential "abductive" powers: they can provide an overall appraisal of the situation at hand and thus orient action. They can be seen as providing abductive "pseudoexplanations" of what is occurring "over there", as it emerges through that material contact with the environment grounded in perceptual interplay. It is through this embodied process that affordances can arise both in wild and artificially modified niches. Peirce had already contended more than one hundred years ago that abduction even takes place when a new born chick picks up the right sort of corn. This is an example, so to say, of spontaneous abduction – analogous to the case of some unconscious/embodied abductive processes in humans.

The original Gibsonian notion of affordance deals with those situations in which the signs and clues the organisms can detect, prompt, or suggest a certain action rather than others. They are immediate, already available, and belong to the normality of the adaptation of an organism to a given ecological niche. Nevertheless, if we acknowledge that environments and organisms evolve and change, and so both their instinctual and cognitive plastic endowments, we may argue that affordances can be related to the variable (degree of) "abductivity" of a configuration of signs: a chair affords sitting in the sense that the action of sitting is a result of a sign activity in which we perceive some physical properties (flatness, rigidity, etc.), and therefore we can ordinarily "infer" (in Peircean sense) that a possible way to cope with a chair is sitting on it. So to say, in most cases it is a spontaneous abduction to find affordances because this chance is already present in the perceptual and cognitive endowments of human and non-human animals.

I maintain that describing affordances that way may clarify some puzzling themes proposed by Gibson, especially the claim concerning the fact that organisms directly perceive affordances and that the value and meaning of a thing is clear on first glance. As I have just said, organisms have at their disposal a standard endowment of affordances (for instance through their wired sensory systems), but at the same time they can plastically extend and modify the range of what can afford them through the appropriate cognitive abductive skills (more or less sophisticated). As maintained by several authors [7, 42–44], what we see is the result of an embodied cognitive abductive process. For example, people are adept at imposing order on various, even ambiguous, stimuli [7, p. 107]. Roughly speaking, we may say that what organisms *see* (or *feel* with other senses) is what their visual (or other senses') apparatus can, so to say, "explain". It is worth noting that this process happens almost simultaneously without any further mediation. Perceiving affordances has something in common with it. Visual perception is indeed a more automatic and "instinctual" activity, that Peirce claimed to be essentially abductive. Indeed he considers inferential any cognitive activity whatever, not only conscious abstract thought: he also includes perceptual knowledge and subconscious cognitive activity. For instance he says that in subconscious mental activities visual representations play an immediate role [45].

We also have to remember that environments evolve and change and so the perceptive capacities especially when enriched through new or higher-level cognitive skills, which go beyond the ones granted by the merely instinctual levels. This dynamics explains the fact that if affordances are usually stabilized this does not mean they cannot be modified and changed and that new ones can be formed.

It is worth noting that the history of the construction of artifacts and various tools can be viewed as a continuous process of building and crafting new affordances upon pre-existing ones or even from scratch. From cave art to modern computers, there has been a co-evolution between humans and the environment they live in. Indeed, what a computer can afford embraces an amazing variety of opportunities and chances comparing with the ones exhibited by other tools and devices. More precisely, a computer as a Practical Universal Turing Machine [46] can mimetically reproduce even some of the most complex operations that the human brain-mind systems carry out (cf. Magnani [19]).

The hypothetical status of affordances reminds us that it is not necessarily the case that just any organisms can detect it. Affordances are a mere potentiality for organisms. First of all perceiving affordances results from an abductive activity in which we infer possible ways to cope with an object from the signs and cues available to us. Some of them are stable and in some cases they are neurally wired in the perceptual system. This is especially true when dealing with affordances that have a high cognitive valence. Perceiving the affordances of a chair is indeed not neurally wired but strongly rooted and stabilized in our cultural evolution. The differences that we can appreciate are mostly *inter-species* – so to speak. A chair affords a child as well as an adult. But this is not the case of a cat. The body of a cat – actually, the cat can sit down on a chair, but also it can sleep on it – has been shaped by evolution quite differently from us.

In higher-level cognitive performances there is something different, since *intra-species* differences seem to be strongly involved. For instance, only a person that has been taught about geometry can infer the affordances "inside" the new manipulated construction built on a geometrical depicted diagram in front of him/her. He/she has to be an "expert". First of all, artificial affordances are intimately connected to culture and the social settings in which they arise and the suitable availability of knowledge of the individual(s) in question. Secondly, affordances deal with learning. There are some affordances like those of an Euclidean triangle that cannot be perceived without a learning process (for instance a course of geometry): people must be somehow *trained* in order to perceive them. Of course acknowledging this last fact places much more emphasis upon the dynamic and also evolutionary character of affordances. The abductive process at play in these cases is very complicated and requires higher level education in cognitive information and skills.

I have already noted that an artificially modified niche (at both levels of biotic and abiotic sources) can be also called "cognitive niche". Recently it has been contended that cognitive niche construction is an evolutionary process in its own right rather than a mere product of natural selection. Through cognitive niche construction organisms not only influence the nature of their world, but also in part determine the selection pressure to which they and their descendants are exposed (and of course the selection pressures to which other species are subjected).

This form of feedback in evolution has been rarely considered in the traditional evolutionary analyses [47]. On this basis a co-evolution between niche construction and brain development and its cognitive capabilities can be clearly hypothesized, a perspective further supported by some speculative hypotheses given by cognitive scientists and paleoanthropologists (for example [16, 17, 48][11]. These authors first of all maintain that the birth of material culture itself was not just the product of a massive "cognitive" chance but also cause of it. In the same light the "social brain hypothesis" (also called "Machiavellian intelligence hypothesis" [49–51]), holds that the relatively large brains of human beings and other primates reflect the computational demands of complex social systems and not only the need of processing information of ecological relevance.

3 Perception as Abduction

3.1 Reifications and Beliefs

Some examples testify how animals are able to form a kind of "concept". These activities are surely at the basis of many possibilities to reify the world. Honey bees are able to learn/form something equivalent to the human concepts of "same" and "different"; pigeons, learn/form such concepts as tree, fish, or human [52, 53]. Sea lions abduce among already formed equivalence classes: a pup's recognition of its mother "[...] depends on the association of many sensory cues with the common reinforcing elements of warmth, contact, and nourishment, while a female recognition of her sisters may depend on their mutual association with the mother" [54].

Something more complicated than classical conditioning is at play when some animals are able to *reify* various aspects of the world using a kind of analogical reasoning. In this way they are able to detect similarities in a certain circumstance, which will be properly applied in a second following situation. Of course this capacity promotes the possibility to form a more contextual independent view about the objects perceived, for example it happens when

[11] I have treated this problem connecting it to some of Turing's insights on the passage from "unorganized" to "organized" brains in a recent article on the role of mimetic and creative representations in human cognition [19].

recognizing similarities in objects that afford food. The mechanism is analogous to the one hypothesized by philosophers and cognitive scientists when explaining concept formation in humans, a process that of course in this case greatly takes advantage of the resources provided by language. This way of thinking also provides the chance of grasping important regularities and the related power to re-identify objects and to predict what has to be expected in certain out-coming situations [54, p. 58]. It is a form of abduction by analogy, which forms something like general hypotheses from specific past event features that can be further applied to new ones.

Bermúdez [18, chapter four] maintains that the process of ascribing thoughts to animals is a form of what Ramsey called "success semantic" [55]. When for example we are confronted by the evidence that a chicken abstains "[. . .] from eating such caterpillars on account of unpleasant experience" a pseudobelief that something is poisonous can be hypothesized and equated to this event. "Thus any set of actions for whose utility P is a necessary and sufficient condition might be called a belief that P, and so would be true if P, i.e., if they are useful" [18, p. 65]. Success semantics adopts a "thought/truth" condition for belief, respecting the idea that thoughts can be true or false because they represent states of affairs as holding: thought is truth-evaluable. Utility condition of a belief is a state of affairs that when holding leads to the satisfaction of desires with which that belief is combined. The satisfaction condition is equally that state of affairs that "[. . .] extinguishes in the right sort of way the behavior to which the desire has given risen. [. . .] The utility condition of a belief in a particular situation is completely open to the third-person perspective of the ethologist or developmental psychologist [. . .] and provides a clear way of capturing how an adaptive creature is in tune with its environment without making implausibile claims at the level of the vehicle of representation" (pp. 65 and 68).

Hence, in success semantics the role of reinforcement through satisfaction is still relevant but it does not impede the fact that also internal representations can be hypothesized, especially when we are dealing with non-basic appetites. Indeed, following Bermúdez, we can say that in some cases representational states are at stake and are directly related to evolutionary pressures: "[. . .] the attunement of a creature to its environment niche is a direct function of the fact that various elements of the subpersonal representational system have evolved to track certain features of the distal environment" [18, p. 69], like in the case of so-called "teleosemantics" [56]. In other cases intelligent skills arise where it is difficult to hypostatize representational contents in situations where evolutionary notions do not play any role: here "Attunement to the environment arises at the level of organism, rather than at the level of subpersonal representational vehicles. That is to say, an organism can be attuned to the environment in a way that will allow it to operate efficiently and successfully, even if there has not been selective pressure for sensitivity at the subpersonal level to the relevant features of the distal environment" [18, p. 69].

3.2 Perception as Abduction

Bermúdez says: "A body is a bundle of properties. But a body is a thing that has certain properties. The simple clustering of collocated features can be immediately perceived, but to get genuine reification there needs to be an understanding (which may or may not be purely perceptual) of a form of coinstantiation stronger that mere spatio-temporal coinstantiation" [18, p. 73]. *Reification* that is behind coinstantiation is not necessarily a matter of the effect generated by the poietic activity of linguistic devices (names for example). Objects over there in the environment, grasped through perception, obey certain principles and behave in certain standard ways that can be reflected and ordered in creatures' brains. To perceive a body is to perceive a cluster of semiotic features that are graspable through different sensory modalities, "but" this process is far beyond the mere activity of parsing the perceptual array. This array has to be put in resonance – to be matched – with already formed suitable configurations of neural networks (endowed with their electrical and chemical processes), which combine the various semiotic aspects arrived at through senses.

These configurations are able for instance to maintain constant some aspects of the environment, like the edges of some standard forms, that also have to be kept constant with respect to kinesthetic aspects related to the motor capabilities of the organism in question. For example these neural configurations compensate variation of size and shape of a distal object with respect to an organism's movements. It is in this sense that we can say, by using a Kantian lexicon, that these neural configurations "construct" the world of the chaotic multiplicity gathered at the level of phenomena. The process is of course very different in different organisms – for example some creatures are not able to retain the size of an object through rotation – but still create a permanent cluster of other appropriate intertwined features[12].

Perception is strongly tied up with reification. Through an interdisciplinary approach and suitable experimentation some cognitive scientists (cf. for example Raftopoulos [60, 61]) have recently acknowledged the fact that in humans perception (at least in the visual case) is not strictly modular, like Fodor [62] argued, that is, it is not encapsulated, hard-wired, domain-specific, and mandatory. Neither is it wholly abductively "penetrable" by higher cognitive states (like desires, beliefs, expectations, etc.), by means of top-down pathways in the brain and by changes in its wiring through perceptual learning, as stressed by Churchland [63]. It is important to consider the three following levels: visual sensation (bodily processes that lead to the formation of retinal image which are still useless – so to say – from the high-level cognitive perspective), perception (sensation transformed along the visual neural pathways in a structured representation), and observation, which consists in all subsequent visual processes that fall within model-based/propositional cognition.

[12] On neural correlates of allocentric space in mammals cf. [57–59].

These processes "[. . .] include both post-sensory/semantic interface at which the object recognition units intervene as well as purely semantic processes that lead to the identification of the array – high level vision" [60, p. 189].

On the basis of this distinction it seems plausible – like Fodor contends – to think there is a substantial amount of information in perception which is theory-neutral. However, also a certain degree of theory-ladenness is justifiable, which can be seen at work for instance in the case of so-called "perceptual learning". However, this fact does not jeopardize the assumption concerning the basic cognitive impenetrability of perception: in sum, perception is informationally "semi-encapsulated", and also semi-hardwired, but, despite its bottom-down character, it is not insulated from "knowledge". For example, it results from experimentation that illusion is a product of learning from experience, but this does not regard penetrability of perception because these experience-driven changes do not affect a basic core of perception[13].

Higher cognitive states affect the product of visual modules only after the visual modules "[. . .] have produced their product, by selecting, acting like filters, which output will be accepted for further processing" [61, p. 434], for instance by selecting through attention, imagery, and semantic processing, which aspects of the retinal input are relevant, activating the appropriate neurons. I contend these processes are essentially *abductive*, as is also clearly stressed by Shanahan [65], who provides an account of robotic perception from the perspective of a sensory fusion in a unified framework: he describes problems and processes like the incompleteness and uncertainty of basic sensations, top-down information flow and top-down expectation, active perception and attention.

It is in this sense that a certain amount of *plasticity* in vision does not imply the penetrability of perception. As I have already noted, this result does not have to be considered equivalent to the claim that perception is not theory-laden. It has to be acknowledged that even basic perceptual computations obey high-level constraints acting at the brain level, which incorporate implicit and more or less model-based assumptions about the world, coordinated with motor systems. At this level, they lack a semantic content, so as they are not learnt, because they are shared by all, and fundamentally hard-wired.

High order physical principles are also important in reification: I have already cited the experiments on dishabituation in nonlinguistic infants and animals, which have shown that sensitivity to some physical principles starts at birth, and so before the acquisition of language both in phylogenetic and ontogenetic terms [18, pp. 78–79]. In these results it is particularly interesting to see how nonlinguistic beings are able to detect that objects continue to exist even if not perceived, thus clearly showing a kind of reification at work in the perception of an organized world.

[13] Evidence on the theory-ladenness of visual perception derived from case-studies in the history of science is illustrated in Brewer and Lambert [64].

In the various nonlinguistic organisms different sets of spatial and physical principles give rise to different ontologies (normally shared with the conspecifics at a suitable stage of development). The problem is to recognize how they are structured, but also how they "evolve". Of course different properties – constant and regular in an appropriate lapse of time – will be salient for an individual at different times, or for different individuals at a given time. This way of apprehending is basically explanatory and thus still abductive (selective or creative) in itself and of course related to the doxastic states I introduced above. Consequently, the "intelligent" organism exhibits a suitable level of flexibility in responding. To make an example, when a mouse is in a maze where the spatial location of food is constant, it is in a condition to choose different paths (through a combination of heuristics and of suitable representations), which can permit it to reach and take the food[14]. This means that in mouse spatial cognition, various forms of prediction/anticipation are at play.

4 Is Instinct Rational? Are Animals Intelligent?

4.1 Rationality of Instincts

Instincts are usually considered irrational or at least a-rational. Nevertheless, there is a way of considering the behavior performances based on them as *rational*. Based on this conclusion, while all animal behavior is certainly described as rational, at the same time it is still rudimentarily considered instinctual. The consequence is that every detailed hypothesis on animal intelligence and cognitive capacities is given up: it is just sufficient to acknowledge the general rationality of animal behavior. Let us illustrate in which sense we have to interpret this apparent paradox. I think the analysis of this puzzling problem can further improve knowledge about model-based and manipulative ways of thinking in humans, offering at the same time an integrated view regarding some central aspects of organisms' cognitive behavior.

Explanations in terms of psychological states obviously attribute to human beings propositional attitudes, which are a precondition for giving a *rational* picture of the explained behavior. These attitudes are a combination of beliefs and desires. Rational internal – doxastic – states characterize human behavior and are related to the fact that they explain why a certain behavior is appropriate on the basis of a specific relationship between beliefs, desires, and actions (cf. Magnani [1, chapter seven]). How can this idea of rationality be extended to nonlinguistic creatures such as human infants and several

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[14] An illustration of the different spatial coordinate systems and their kinesthetic features in rat navigation skills (egocentric, allocentric, in terms of route in a maze space, etc.) is given in the classical Tolman, Ritchie, and Kalish [66], O'Keefe and Nadel [67], Gallistel [68].

types of animals, where the role of instinct is conspicuous? How can the inferential transformations of their possible internal thoughts be recognized when, even if conceivable as acting in their nervous systems, these thoughts do not possess linguistic/propositional features?

The whole idea of rationality in human beings is basically related to the fact we are able to apply *deductive* formal-syntactic rules to linguistic units in a truth preserving way, an image that directly comes from the tradition of classical logic: a kind of rationality robustly related to "logico-epistemological" ideals. The computational revolution of the last decades has stressed the fact that rationality can also be viewed as linked to ways of thinking such as *abduction* and *induction*, which can in turn be expressed through more or less simple *heuristics*. These heuristics are usually well-assessed and shared among a wide community from the point of view of the criteria of applicability, but almost always they prove to be strongly connected in their instantiation to the centrality of language. Indeed cognitive science and epistemology have recently acknowledged the importance of model-based and manipulative ways of rational thinking in human cognition, but their efficacy is basically considered to be strictly related to their hybridization with the linguistic/propositional level. Consequently, for the reasons I have just illustrated, it is still difficult to acknowledge the rationality of cognitive activities that are merely model-based and manipulative, like those of animals.

At the beginning of this section I said that, when dealing with rationality in nonlinguistic creatures, tradition initially leads us to a straightforward acknowledgment of the presumptive and intrinsic "rationality" of instincts. The background assumption is the seeming impossibility that something ineluctable like instinct cannot be at the same time intrinsically rational. Of course the concept of rationality is in this case paradoxical and the expression "rationality" has to be taken in a Pickwickian sense: indeed, in this case the organisms at stake "cannot" be irrational. A strange idea of rationality! Given the fact that many performances of nonlinguistic organisms are explainable in terms of sensory preconditioning (and so are most probably instinct-based – hard-wired – and without learnt and possibly conscious capacities which enable them to choose and decide), the rationality of costs and benefits in these behaviors is expressed in the "non-formal" terms of Darwinian "fitness". For example, in the optimal foraging theory, "rationality" is related to the animal's capacity – hard-wired thanks to evolution – to optimize the net amount of energy in a given interval of time. Contrarily to the use of some consciously exploited heuristics in humans, in animals many heuristics of the same kind are simply hard-wired and so related to the instinctual adaptation to their niches.

The following example provided by Bermúdez can further clarify the problem. "Redshanks are shorebirds that dig for worms in estuaries at low tide. It has been noticed that they sometimes feed exclusively on large worms and at other times feed on both large and small worms. [...] In essence, although a large worm is worth more to the red shank in terms of quantity of energy gained per unit of foraging time than a small worm, the costs of searching exclusively for large worms can have deleterious consequences, except when the large worms are relatively plentiful" [18, p. 117]. The conclusion is simple: even if the optimal behavior can be described in terms of a "rational" complicated version of expected utility theory, "[...] the behaviors in which it manifests itself do not result from the application of such a theory" (*ibid.*). We can account for this situation in our abductive terms: the alternatives which are "abductively" chosen by the redshanks are already wired, so that they follow hardwired algorithms developed through evolution, and simply instantiate the idea of abduction related to instincts present in Peircean insights.

The situation does not change in the case that we consider short-term and long-term rationality in evolutionary behaviors. In the case of the redshank we deal with "short-term" instinct–based rationality related to fitness, but in the case of animals that sacrifice their lives in a way that increases the lifetime fitness of other individuals we deal with "long-term" fitness. It has to be said that sometimes animals are also "hardwired" to use external landmarks and territory signs, and communicate with each other using these threat-display signals that consent them to avoid direct conflict over food. These artifacts are just a kind of instinct-based *mediators*, which are "instinctually" externalized and already evolutionarily stabilized[15].

4.2 Levels of Rationality in Animals

Beyond the above idea of "rationality" in animals and infants as being related to tropistic behaviors connected to reflexes and inborn skills such as imprinting or classical conditioning, the role of intermediary internal representations has to be clearly acknowledged. In this last case we can guess that a "rational" intelligence closer to the one expressed in human cognition, and so related to higher levels of abductive behavior, is operating. We fundamentally deal with behaviors that show the capacity to choose among different outcomes, and which can only be accounted for by hypothesizing learnt intermediate representations and processes. In some cases a kind of decision-making strategy can also be hypothesized: in front of a predator an animal can fight or flee and in some sense one choice can be more rational than the other. In front of the data, to be intended here as the "affordances" in a Gibsonian sense, provided through mere perception and which present various possibilities for action, a high-level process of decision-making is not needed, but choice is still possible. With respect to mere wired capacities the abductive behavior above seems based on reactions that are more flexible.

[15] These mediators are similar to the cognitive, epistemic, and moral mediators that humans externalize thanks to their plastic high-level cognitive capacities, but less complex and merely instinct-based. I have fully described the role of epistemic mediators in scientific reasoning in [7], and of moral mediators in ethics in [1]. See also the following section.

Bermúdez [18, p. 121] labels Level 1 this kind of rationality. It differs from "rationality" intended as merely instinct-based, expressed in immutable rigid behaviors (called Level 0). Level 1 rationality (which can still be split in short-term and long-term) is for example widespread in the case of animals that entertain interanimal interactions. This kind of rationality would hold when we clearly see ir-rational animals, which fail to signal to the predator and instead flee, thus creating a bad outcome for group fitness (and for their own lifetime fitness: other individuals will cooperate with them less in the future and it will be less probable for them to find a mate).

To have an even higher level rationality (Level 2) we need to involve the possibility of abductively selecting among different "hypotheses" which make the organisms able – so to say – to "explain" certain behaviors: a kind of capacity to select among different "hypotheses" about the data at hand, and to behave correspondingly. This different kind of "rational" behavior, is neither merely related to instincts nor simply and rudimentarily flexible, like in the two previous cases.

To make the hypothesis regarding the existence of this last form of rationality plausible, two epistemological pre-conditions have to be fulfilled. The first is related to the acknowledgment that model-based and manipulative cognitions are endowed with an "inferential" status, as I explained above when dealing with the concept of abduction, taking advantage of the semiotic perspective opened up by Peirce. The second relates to the rejection of the restricted logical perspective on inference and rationality I have described in the previous subsection, which identifies inferences at the syntactic level of natural and artificial/symbolic languages (in this last case, also endowed with the truth-preserving property, which produces the well-known isomorphism between syntactic and semantic/content level).

At this high-rationality level we can hypothesize in nonlinguistic organisms more than the simple selection of actions, seen as merely wired and operating at the level of perceptions like the theory of immediate affordances teaches, where a simple instrumental conditioning has attached to some actions a positive worth. Instead, in Level 2 rationality, complicated, relatively stable, internal representations that account for consequences are at work. In this case selecting is selecting – so to speak – for some "reasons": a bird that learns to press a lever in a suitable way to obtain food, which will then be delivered in a given site, acts by considering an association between that behavior and the consequences. A kind of instrumental pseudobelief about the future and about certain probable regularities is established, and contingencies at stake are represented and generalized in a merely model-based way. Then the organism internally holds representations with some stability and attaches utility scores to them: based on their choice a consequent action is triggered, which will likely satisfy the organism's desire. The action will be stopped, in a nonmonotonic way, only in the presence of out-coming obstacles, such as the presence of a predator.

Of course the description above suffers the typical anthropomorphism of the observer's "psychological" explanations. However, beliefs do not have to be considered explicit; nevertheless, some actions cannot be explained only on the basis of sensory input and from knowledge of the environmental parameters. Psychological explanations can be highly plausible when the goal of the action is immediately perceptible or when the distal environment contains immediately perceptible instrumental properties. This is obvious and evident in the case of human beings' abilities, but something similar occurs in some chimpanzees' behavior too. When chimpanzees clearly see some bananas they want to reach and eat, and some boxes available on the scene, they have to form an internal instrumental belief/representation on how to exploit the boxes. This "pseudobelief" is internal because it is not immediately graspable through mere perceptual content:

> Any psychological explanation will always have an instrumental content, but the component needs not take the form of an instrumental belief. [...] instrumental beliefs really only enter the picture when two conditions are met. The first is that the goal of the action should not be immediately perceptible and the second is that there should be no immediately perceptible instrumental properties (that is to say, the creature should be capable of seeing that a certain course of action will lead to a desired result). The fact, however, that one or both of these conditions is not met does not entail that we are dealing with an action that is explicable in non-psychological terms. [18, p. 129]

The outcomes are represented, but these "pseudorepresentations" lack in lower kinds of rationality. The following example is striking. A food source was taken away from chicken at twice the rate they walked toward it but advanced toward them at twice the rate they walked away from it: after 100 trials, this did not affect the creatures' behavior which failed to represent the two contingencies ([69] quoted in [18, p. 125]). Chicken, which do not retreat from a certain kind of action faced with the fact that a repeated contingency no longer holds, are not endowed with this high level "representational" kind of abductive rationality.

5 Artifactual Mediators and Languageless Reflexive Thinking

5.1 Animal Artifactual Mediators

Even if the animal construction of external *artifactual mediators* is sometimes related to instinct, as I have observed in the subsection 4.1, it can also be the fruit of plastic cognitive abilities strictly related to the need to improve actions and decisions[16]. In this case action occurs through the expert delegation of

[16] I have already stressed that plants also exhibit interesting plastic changes. In resource-rich productive habitats where the activities of the plants "generate"

cognitive roles to external tools, like in the case of chimpanzees in the wild, that construct wands for dipping into ant swarms or termite nests. These wands are not innate but highly specialized tools. They are not merely the fruit of conditioning or trial and error processes as is clearly demonstrated by the fact they depend on hole size and they are often built in advance and away from the site where they will be used.

The construction of handaxes by the hominids had similar features. It involved paleocognitive model-based and manipulative endowments such as fleeting consciousness, private speech, imposition of symmetry, understanding fracture dynamics, ability to plan ahead, and a high degree of sensory-motor control. I have already said in subsection 1.1 they represent one of the main aspects of the birth of *material culture* and technical intelligence and are at the root of what it has been called the process of a "disembodiment of mind" [16, 19].

From this perspective the construction of artifacts is an "actualization" in the external environment of various types of objects and structures endowed with a cognitive/semiotic value for the individual of for the group. Nonlinguistic beings already externalize signs like alarm calls for indicating predators and multiple cues to identify the location of the food caches, which obey the need to simplify the environment and which of course need suitable spatial memory and representations [71, 72]. However, animals also externalize complicated artifacts like in the case of Darwin's earthworms that I have illustrated in subsection 1.1.

These activities of cognitive delegation to external artifacts is the fruit of expert behaviors that conform to innate or learnt embodied templates of cognitive doing. In some sense they are analogous to the templates of epistemic doing I have illustrated in [7], which explain how scientists, through appropriate actions and by building artifacts, elaborate for example a simplification of the reasoning task and a redistribution of effort across time. For example, Piaget says, they "[...] need to manipulate concrete things in order to understand structures which are otherwise too abstract" [73] also to enhance the social communication of results. Some templates of action and manipulation, which are implicit and embodied, can be *selected* from the set of the ones available and pre-stored, others have to be *created* for the first time to perform the most interesting creative cognitive accomplishments of manipulative cognition.

Manipulative "thinking through doing" is creative in particularly skilled animals, exactly like in the case of human beings, when for example chimpanzees make a "new" kind of wand for the first time. Later on the new

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various resources above and below ground that strongly modify the environment, plants themselves exhibit various kinds of, so-called, morphological plasticity – that is, the replacement of existing tissues [13, p. 300]. It is important to note that plant plasticity is particularly advantageous when responses are reversible rather than irreversible [70].

behavior can possibly be imitated by the group and so can become a shared "established" way of building artifacts. Indeed chimpanzees often learn about the dynamic of objects from observing them manipulated by other fellows: a process that enhances social formation and transmission of cognition.

5.2 Pseudological and Reflexive Thinking

Among the various ways of model-based thinking present in nonlinguistic organisms, some can be equated to well-known inferential functional schemes which logic has suitably framed inside abstract and ideal systems. There are forms of pseudological uses of negation (for example dealing with presence/absence, when mammals are able to discern that a thing cannot have simultaneously two contrary properties), of *modus ponens* and *modus tollens* (of course both related to the presence of a pseudonegation), and of conditionals (cf. Bermúdez [18, chapter seven]). Of course, these ways of reasoning are not truth preserving operations on "propositions" and so they are not based on logical forms, but it can be hypothesized that they are very efficient at the nonlinguistic level, even if they lack an explicit reference to logical concepts and schemes[17]. They are plausibly all connected with innate abilities to detect regularities in the external niche. In addition, forms of causal thinking are observed, of course endowed with an obvious survival value, related to the capacity to discriminate causal links from mere non-causal generalizations or accidental conjunctions[18].

It is interesting to note in prelinguistic organisms the use of both "logical" and fallacious types of reasoning. For example the widespread use of "hasty generalization" shows that poor generalizations must not only be considered – in the perspective of a Millian abstract universal standard – as a bad kind of induction. Even if hasty generalizations are considered bad and fallacious in the light of epistemological ideals, they are often strategic to the adaptation of the organism to a specific niche [77].

An open question is the problem of how nonlinguistic creatures could possess second-order thoughts on thoughts (and so the capacity to attribute thoughts to others) and first – and second-order – desires (that is desires when one should have a specific first-order desire). In human beings, self-awareness and language are the natural home for these cognitive endowments. Indeed,

[17] On the formation of idealized logical schemes in the interplay between internal and external representations cf. [74].

[18] Human prelinguistic infants show surprise in front of scenes when "action at a distance" is displayed (it seems they develop a pseudothought that objects can only interact causally through physical contact) [75]. Some fMRI experiments on "perceptual" causality are described in [76]: specific brain structures result involved in extracting casual frameworks from the world. In both children and adults these data show how they can grasp causality without inferences in terms of universality, probability, or casual powers.

it is simple to subsume propositions as objects of further propositions for ourselves and for others, and consequently to make "reflexive" thinking possible. This kind of thinking is also sensitive to the inferences between thoughts, which are suitably internally represented as icons of written texts or as representations of our own or others' external voices. In addition, the use of external propositional representations favors this achievement, because it is easy to work over there, in an external support, on propositions through other propositions and then internally recapitulate the results.

If it is difficult to hypothesize that animals and early infants can attribute beliefs and desires to other individuals without the mediation of language and of what psychologists call the "theory of mind", but it is still plausible to think that they can attribute goal-desires to other individuals. In this sense they still attribute a kind of intentionality, and are consequently able to distinguish in other individuals between merely instinctive and purposeful conducts[19].

In human beings, intentional attitudes are attributed by interpreters who abductively undertake what Dennett [80] calls the "intentional stance": they abduce hypotheses about "intentions". These attributions are "[...] ways of keeping track of what the organism is doing, has done, and might do" [81, p. 73]. However, animals too have the problem of "keeping track" of the behavior of other individuals. For example, it is very likely they can guess model-based abductive hypotheses about what other organisms are perceiving, even if those perceptions are not comprehended and made intelligible through the semantic effect produced by language, like in humans[20]. The importance of this capacity to monitor and predict the conduct of conspecifics and/or predators is evident, but other individuals are not seen as thinkers, instead they are certainly seen as doers.

Recent research has shown in animals various capacities to track and "intentionally" influence other individuals' behavior[21]. Tactical deception takes advantage of the use of various semiotic and motor signs in primates: for example, some females, by means of body displacements not seen by a dominant male, can cheat him when they are grooming another non-dominant male [82]. Ants, through externalized released pheromone, deceive members of other colonies: these signs/signals play the role of indirect exchanges of chemicals as units of cheating communication[22]. These activities of deception can be seen in the light of the ability to alter other individuals' sensory perceptions. The case of some jumping hunting spiders illustrated by Wilcox and Jackson

[19] Recent research on mirror neurons in primates and human beings support the neurological foundation of this ability [78, 79].

[20] On the encapsulation of perception in language in humans cf. subsection 3.2.

[21] Of course these capacities can be merely instinct-based and the fruit of a history of selection of certain genetic "programs", and consequently not learned in particular environmental contingencies, like in the cases I am illustrating here.

[22] Cf. Monekosso, Remagnino, and Ferri [83] that also illustrate a computational learning program which makes use of an artificial pheromone to find the optimal path between two points in a regular grid.

is striking. By stalking across the web of their prey, they cheat it, through highly specialized signals, also suitably exploiting aggressive mimicry. The interesting thing is that they plastically adapt their cheating and aggressive behavior to the particular prey species at stake, all this by using a kind of trial and error tactic of learning, also reverting to old strategies when they fail [84].

To conclude, it can be conjectured that, at the very least, emotions in animals can play a kind of reflexive role because they furnish an appraisal of the other states of the body, which arise in the framework of a particular perceptual scenario. This fact clearly refers to another kind of reflexivity, distant from the one that works in beings able to produce thoughts of thoughts, attribute thoughts to others (so possessing a "theory of mind"), monitor thoughts and belief/desire generation and engage in self-evaluation and self-criticism[23]. Also in adult humans emotions play this reflexive role, but in this case usually emotions are trained and/or intertwined with the effects produced by culture and thus language[24]. It seems researchers agree in saying that propositions/sentences are the only suitable mediators of second order thoughts. It is plausible to conclude that nonlinguistic creatures are excluded from many typically human ways of thinking, and it is plausible to guess that this reciprocally happens for humans, who do not possess various perceptual and cognitive skills of animals.

5.3 Affect Attunement and Model-Based Communication

An interesting extension of the model I have introduced in my recent [26], concerning "mimetic and creative representations" in the interplay between internal/external is furnished by the merely model-based case of some nonlinguistic and prelinguistic living beings. Human infants entertain a coordinated communication with their caregivers, and it is well known that many psychoanalysts have always stressed the importance of this interplay in the further development of the self and of its relationships with the unconscious states. Infants' emotional states, as "signs" in a Peircean sense, are displayed and put out into the external world through the semiotic externalization of facial expressions, gestures, and vocalizations. The important fact here is that this cognitive externalization is performed in front of a living external "mediator", the mother, "the caregiver", endowed with a perceptual system that can grasp the externalized signs and send a feedback: she cognitively and affectively mediates the initial facial expression and the interplay among the subsequent ones. The interplay above is also indicated as a case of human *affective attunement* [85].

In general an agent can expect a feedback also after having "displayed" suitable signs on a non living object, like a blackboard, but it is clear that

[23] Nevertheless, we have seen that nonlinguistic organisms "can" revise and change their representations.

[24] Cf. Magnani [1, chapter six].

in this last case a different performance is at play, which involves explicit manipulations of the external object, and not a mere exchange of – mainly facial-based – sensations, like in affective attunement. The external delegated representation to a non living object shows more or less complicated active responses, which are intertwined with the agent's manipulations. For example, a blackboard presents intrinsic properties that limit and direct the manipulation in a certain way, and so does a PC, which has – with respect to the blackboard – plenty of autonomous possibility to react: usually the interplay is hybrid, taking into account both propositional, iconic (in a Peircean sense), and of course motor aspects[25].

In affect attunement, the interplay is mainly model-based and mostly iconic (also taking advantage of the iconic force of gestures[26] and voice), meaningful words are also present, but the semiotic "propositional" flow is fully understood only on the part of the adult, not on the part of the infant, where words and their meanings are simply being learnt. The infant performs an "expressive" behavior based on appearances and gestures that are spontaneously externalized to get a feedback. Initially the expressions externalized are directly *mimetic* of the inner state but – through the interplay – where subsequent recapitulations of the mother's facial expressions are performed and are gradually, suitably picked up "outside" the mom's body, novel "social" expressions are formed. These expressions are shared with the mom and thus they are no longer arbitrary. Once stabilized, they constitute the expected affective "attunement" to the mom/environment, which is the fruit of a whole abductive model-based activity of subsequent "facial hypotheses". In this process, the external manifestation of the nonlinguistic organism is established as the quality of feelings that testify a shared affect. A new way of sharing affect is abductively *created*, which is at the basis of the further social expression of emotions.

In the case of externalization of signs in non-human animals, when the sharing of affect is not at play, we are, for example, faced with the mere communication of useful information. Many worker honeybees socially externalize dances that express the site where they have found food to inform the other individuals about the location:

> [...] the waggle dances communicate information about direction, distance, and desirability of the food source. Each of these three dimensions of variation is correlated with a dimension of variation in the dance. The angle of the dance relative to the position of the sun indicates the direction of food source. The duration of a complete

[25] It has to be noted that for Peirce iconic signs are generally arbitrary and flexible but there are some symbols, still iconic, which are conventional and fixed, like the ones used in mathematics and logic.

[26] Mitchell [86] contents infants need a connection between kinesthesis and vision. That is, without this connection the organism would not be able to connect the kinesthetic image it has of its own body with any visual image.

> figure-of-eight circuit indicates the distance to the food source (or rather the flying time to the food source, because it increases when the bees would have to fly into a headwind). And the vigor of the dance indicates the desirability of the food to be found. [18, p. 152][27]

The externalized figures performed through movements are agglomerative[28] signs that grant a cognitive – communicative – *mediator* to the swarm. Through this interplay with other bees, the dancers can get a feedback from the other individuals, which will help them later on to refine and improve their exhibition. In the case of animals, which perform these kinds of externalizations on a not merely innate basis, the true "creation" of new ways of communicating can also be hypothesized, through the invention of new body movements, new sounds or external landmarks, which can be progressively provided, if successful, as a cognitive resource to the entire group.

Related to both the infant affect attunement and bee dances illustrated above an epistemological remark is fundamental. When we speak about internal and external representations in the abductive interplay we put ourselves in the perspective of the researcher, who "sees" two or more different agents in the sense of folk psychology. Nevertheless, in the two examples, the agents are not reified in the sense that "they" do not perceive "themselves" as agents, like we instead do. Rather, for instance in the case of affect attunement, it is the process itself that is responsible for the formation of the infant's agentive status. A clarification of this problem can be found in some cognitive results derived form neurological research, which I have described in a forthcoming paper [89].

6 Conclusion

The main thesis of this paper is that model-based reasoning represents a significant cognitive perspective able to unveil some basic features of abductive cognition in non-human animals. Its fertility in explaining how animals make up a series of signs and are engaged in making or manifesting or reacting to a series of signs in instinctual or plastic ways is evident. Indeed in this article I have illustrated that a considerable part of this semiotic activity is a continuous process of "hypothesis generation" that can be seen at the level of

[27] Bees would certainly find human communication very poor because we do not inform our fellows on the location of the closest restaurant by dancing!

[28] The theoretical distinction between agglomerative diagrammatic signs and discursive signs in sentential reasoning, together with many other fundamental clarifications of Peircean insights, also concerning mathematical reasoning, are given in Stenning [87]. On the cognitive advantages (and also disadvantages) – in humans – of diagrammatic dynamic reasoning over sentential reasoning cf. Jones and Scaife [88]: in a watcher/user/learner better cognitive offloading is allowed by external diagrammatic dynamic representations and their "hidden" dependencies.

both instinctual behavior and representation-oriented behavior, where non-linguistic pseudothoughts drive a "plastic" model-based cognitive role. I also maintain that the various aspects of these abductive performances can also be better understood by taking some considerations on the concept of affordance into account. From this perspective the referral to the central role of the externalization of artifacts that act as mediators in animal languageless cognition becomes critical to the problem of abduction. Moreover, I tried to illustrate how the interplay between internal and external "pseudorepresentations" exhibits a new cognitive perspective on the mechanisms underling the emergence of abductive processes in important areas of model-based inferences in the so-called mindless organisms.

The paper also furnished further insight on some central problems of cognitive science. I maintain that analysis of the central problems of abduction and hypothesis generation in non-human animals further clarifies other related topics in model-based reasoning, like pseudological and reflexive thinking, the role of pseudoexplanatory guesses in plastic cognition, the role of reification and beliefs, the problem of the relationship between abduction and perception, and between rationality and instincts, and the issue of affect attunement as a fundamental kind of model-based abductive communication.

In summary, in light of the considerations I outline in this paper it can be said that a considerable part of abductive cognition occurs through model-based activity that takes advantage of pseudoexplanations, reifications in the external environment, and hybrid representations. An activity that is intrinsically *multimodal*. This conclusion rejoins what I have already demonstrated in my recent article [90], from the perspective of distributed cognition: abductive hypothetical cognition involves a full range of various sensory modalities, which clearly stress its multimodal character.

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