Species-Specific Knowledge About the Environment: A Biophilosophical View

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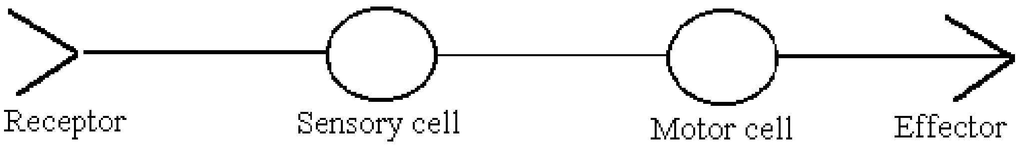
1. Introduction

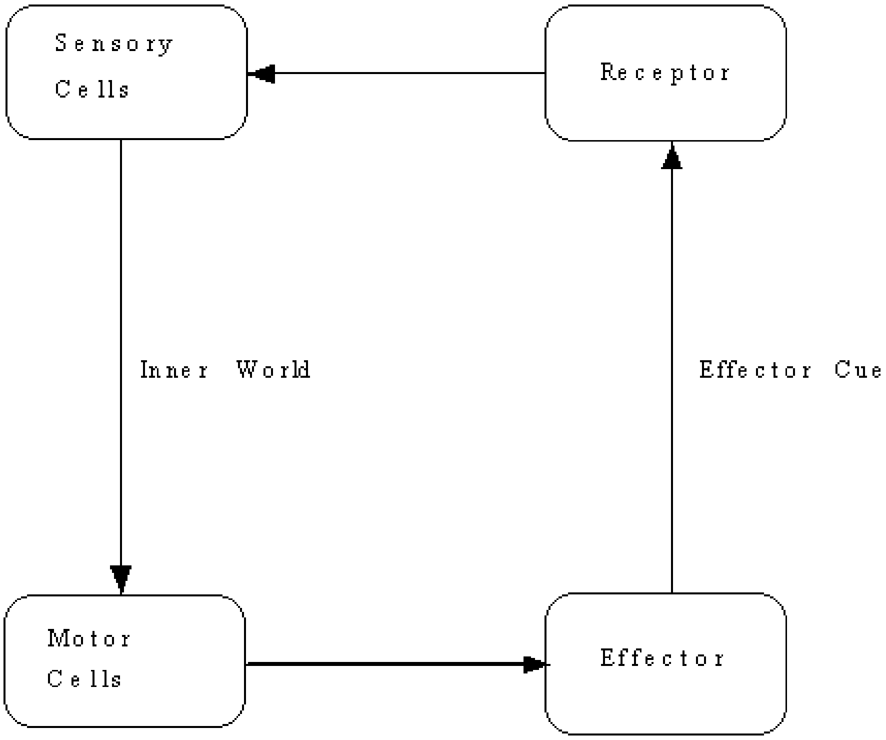
The biological work of Jacob von Uexkull (1934) raised an hypothesis that different animal species living in the same environment would have different knowledge about it. He suggested that each species perceives the world according to the structure of their effectors. In this essay I discuss mechanisms in the animal brain possibly responsible for the "embodied" or "pragmatic" character of cognition.

2. The Cognitive Cycle

The simplest representation of cognitive processes in the animal nervous system is the "reflex arc":



According to this model, cognitive processes are merely a conversion of sensory input into motor control. The feedback of motor activity upon the sensory subsystem is not considered. Uexkull alternatively proposed that knowledge is produced in a "functional cycle":



The diagram shows a cycle between perceptions and actions of an organism, leading to the formation of an "inner world" (the "Umwelt"). In this model, cyclic interactions between the organism and the environment (in phylogeny as in ontogeny) determine how the organism perceives the external world; in von Uexkull's words, "the limbs or other organs activated by the separate muscles imprint upon the external objects their effector cue or functional significance...the traits given operational meaning must affect those bearing perceptual meaning" (von Uexkull, 1934).

3. Mechanisms of Reafference

In the fifties and sixties, models of the nervous system included mechanisms by which the action system sends signals to the perceptual system. Three different pathways were identified:

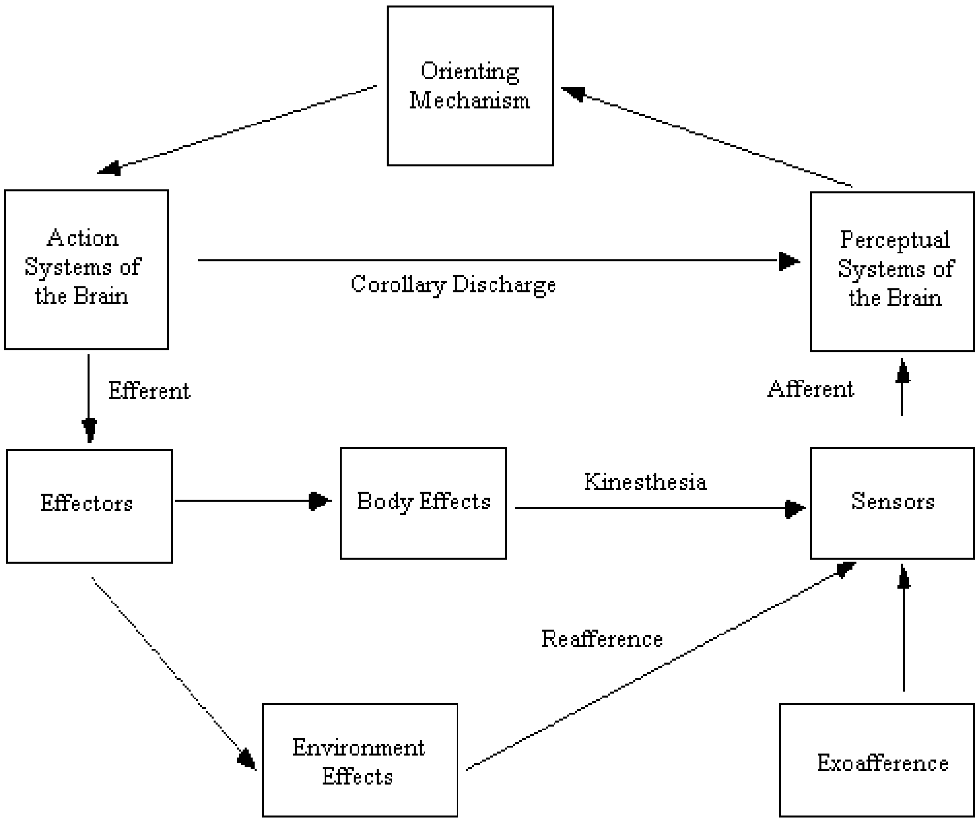
a) at the same time that the action is triggered in the CNS, a signal may be sent directly to the perceptual system. Some hypotheses concerning this alternative include the "corollary discharge" (Sperry, 1950, Hein & Held, 1962) and the "efference copy" (von Holst and Mittlelstadt, 1950), supported by interesting experiments (these hypotheses are discussed in McCloskey, 1977, and Clark & Horch, 1986);

b) when an action is performed, the internal sensors of the body (e.g. kinesthetic sensors) send signals to the perceptual system;

c) the performed action produces consequences on the external environment, and/or in the position of the external sensors, that signals to the perception system. This pathway consists of an "external loop (Held and Hein, 1958), where e.g. motor activity is perceived by visual sensors, and/or produces changes in visual perception.

Besides receiving signals from the action system and from external events influenced by previous actions of the organism, peripheral sensors also receive other signals, from the body and environment, that are independent of previous actions. These signals are called *exoafferent* (McCloskey, 1977).

The systems and their connections are summarized in the following diagram. The connections between sensors, spinal cord and action effectors, involved in automatic behaviors, are omitted.



4. The Orienting System

The above diagram includes an "orienting system", responsible for the definition of the kind of behavior to be performed, compatible with the perceived stimuli. The most basic kinds of behavior are feeding, fleeing, fighting and reproduction.

The existence of an orienting system is probably widespread along the phylogenetic scale, covering at least all species that have a limbic cortex. The patterns of behavior defined by the orienting system alone are stereotyped, as proposed in Lorenz' concept of "fixed patterns" (Lorenz and Tinbergen, 1938; Lorenz, 1952). An example of a stereotyped response is the "orienting reflex" studied by Sokolov (1975).In this expression, the word "reflex" doesn't mean a response elicited by an external conditioning; on the contrary, it refers to an unconditional instinct, that guides behavior, in the following kinds of situations:

a) when a stereotyped pattern is initiated, without being triggered by a specific stimulus, e.g., a chicken searching for food, in the absence of any specific food stimulus;

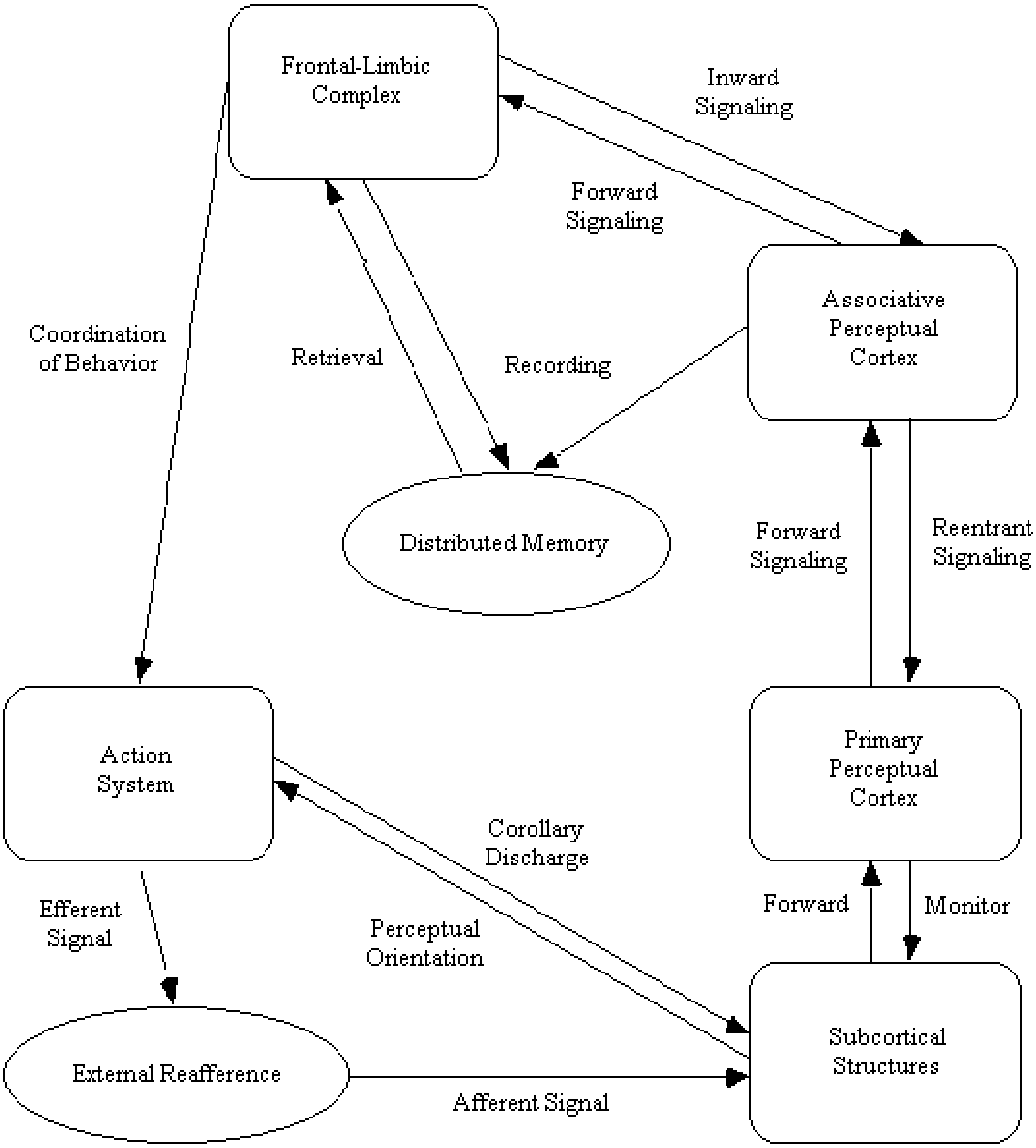
b) when a stereotyped pattern is triggered by a specific stimulus, e.g., a predator-like sound inducing the prey to escape;

c) when there is a stereotyped reaction to a change in an habitual environmental setting, e.g., the miller who wakes up when the noisy mill stops working.

5. The Attentional System

Along the evolution of the brain, new cortical structures emerged, increasing the flexibility of behavior. The structures, that include limbic, cerebellar and neocortical networks, are connected to perception and action systems. They control the perceptual focus, according to learned biases (perceptual attention) **and** support the "planning" of actions, using learned strategies (executive attention - see Posner, 1995).

The attentional system is anatomically entangled with the orienting system. The distinction between them depends on theoretical assumptions about the cognitive functions that they support. In the primate brain, the attentional system comprises largely interconnected limbic and prefrontal structures. The functional organization of the primate brain may be visualized in the diagram:



6. Recognition

"Recognition" is a term widely used in cognitive neuroscience. In a common sense, the term means the attribution of "meaning" to stimuli patterns. It is used in a biological, not linguistic sense. A stimulus has a biological meaning for an organism if a critical number of receptive fields of neurons react (i.e., fire) to the presentation of the stimulus. The operation of recognition doesn't imply the formation of a theoretical knowledge about the stimulus. Such philosophical connotation is not adequate for the use of the term in neuroscience.

Recognition should be understood as the work of the whole perceptual system, and not as the work of a specialized part (a "module") alone. Neuroscientific studies on recognition have mostly focused on the visual system. The process of visual recognition has two continuous stages. The relatively high spatial resolution of visual perception is supported by the multi-channeled structure of the retina and optical nerves. Such structure allows the functional property of *retinotopy* or isomorphic transformation from the stimulus to the retina, and from the retina through a bundle of fibers to the thalamus and primary visual areas of the cortex. The second part is performed by the posterior parietal ("where" pathway) and infero-temporal cortex ("what" pathway). Visual recognition should not be considered only the "high level" perceptual operation made by such "associative areas". It is also dependent on the structures that perform the first stage.

A detailed analysis of recognition reveals four important aspects:

a) Recognition Is a Dynamical Process

Recognition processes consist a matching of two patterns, one of them coming from the stimuli and the other present at the receptive field of neurons. The second form is a product of previous learning and endogenous mechanisms (rhythmic patterns, as alpha, gamma and theta rhythms).

The process of recognition is completely different from formal identity. To identify two things at the formal level (e.g., in the workings of a digital computer) is just to ascribe the same symbol to them. Recognition, on the other hand, is a process where two dynamical, structured (autocorrelated) temporal forms interact. The product of the interaction depends on the initial state and on the context; e.g., Sokolov noted that the presentation of a habitual stimulus doesn't elicit a recognition process, but the withdrawal of such stimulus does.

b) Recognition Is a Distributed Process

The dynamical aspect of recognition is consistent with the idea that neurons operate with a temporal code (Cariani, 1994). Recognition processes would be closer to the conception of neurons as oscillators, instead of simple electronic filters. The matching of two patterns requires a temporal duration for them to interact. Different oscillators working at the same time need spatial separation. Such aspects of recognition would explain why parallel distributed perform better than serial models of recognition.

Another reason why recognition processes are not well described by serial models is that perceptual systems in the brain have many convergent and divergent pathways (Freeman, 1995). The retinotopic (one-to-one) transformations in the visual systems would be an exception, not the rule. Convergent pathways are necessary for the operation of coincidence detectors, a neuronal mechanism essential to perceptual processing (Cariani, 1994).

c) Recognition is Selective

Only (biologically) meaningful patterns are processed by the nervous system. The restriction comes from adaptive constraints in the evolution of biological organisms. The presence of genetic and attentional mechanisms makes recognition processes *selective* at two levels: phylogenetic and attentional. Phylogenetic selectivity means that each species is structurally (genetically determined) able to perceive only the kinds of stimuli for which perceptual sensors and central analysers were developed in evolution. Attentional selectivity is relative to an individual, in a specific situation; it doesn't imply that the organism perceives only the relevant aspects of the stimuli, but postulates the existence of a bias for highlighting such aspects.

d) Recognition Involves Reciprocal Causality

Maybe the most important epistemological aspect of recognition is that it affects the cognitive system both structurally and functionally. During a process of recognition, the cognitive system reconstructs the patterns being perceived, and is reciprocally shaped by the patterns that it recognizes. Such reciprocity is a consequence of the *plasticity* of neuronal networks.

Reciprocal causality in perceptual systems may be described as an interaction of "bottom up" (stimulus-guided) and "top down" (attentional) processes. A model that accounts for the interplay of "top-down" and "bottom-up" processes is the Adaptive Resonance Theory (see e.g. Grossberg, 1995). The idea of a *resonance* between two layers, one sensitive to the stimuli patterns and the other shaped by previous learning, is an adequate concept of reciprocal causality available in contemporary cognitive neuroscience. This kind of model helps explaining the workings of diverse brain subsystems that match afferent information with previously learned forms (e.g., the visual system, the hippocampus, the cerebellum, etc.).

7. Pragmatic Representations

The cognitive units of the brain are those that perform recognition; all other cognitive operations are dependent upon them. The brain *represents* informational patterns only *after* such patterns are *recognized*. Representations are based both in the spatial distribution and temporal form of the neuronal activity involved in recognition. An electrochemical code is necessary for the transfer of previously recognized patterns from one to other part of the brain. Previously recognized patterns are encoded in electrochemical patterns, and then recombined, generating composite patterns that support self-determined behavior. In mammals such combinatory process includes the planning of actions, the representation of goals and respective goal-directed behavior.

The functions of the orienting and attentional systems have an interesting epistemological consequence: representations constructed by animal brains are *pragmatic* (Clark, 1996; Cisek, 1998). They are not representations of infinite aspects of the environment, or "essential" aspects. They are representations of the aspects that are relevant for the animal: those aspects that, in phylogenetic and ontogenetic scales, are involved in the actions of the animal.

As the repertory of possible actions of animals depends on the structure of their effectors and on the orienting mechanism that defines the action appripriate to the context, each species sharing a common environment is likely to construct different representations of it. Knowledge construction is also sensible to individual differences within populations. Each species and each individual is likely to focus attention to the aspects of the environment that are relevant for the actions that support their survival in that context.

Working together, orienting and attentional mechanisms are responsible for biasing the knowledge of each biological individual. The interaction of both mechanisms generates, in animals having a complex Central Nervous System, an "internal feedback", the biasing of attention according to the intentions of the action the animal is engaged in.

8. Implications for Epistemology

Epistemological theories have been deeply influenced by the opposition between Empiricism and Rationalism. The first emphasized the determining role of environmental stimuli, and the second the role of 'a priori' forms of sensibility and understanding. Some attempts to overcome the opposition are Hegelian and Marxian dialectics, Peircean and Jamesian pragmatism, and Piagetian interactionism.

The biological model above goes beyond the simple interaction of "subject" and "object". It suggests that knowledge in produced in a *cycle* of perceptions and actions of a living being - Uexkull's "functional cycle". What is perceived influences the action being performed, and the consequences of action influences the subsequent perception. Details of this cyclical process are being studied by contemporary cognitive neuroscience and robotics, opening new possibilities of collaboration between philosophers and scientists.

Acknowledgements: this work was written during a Post-Doctoral period at the Massachusetts Institute of Technology/USA, under the supervision of Prof. Stephan L. Chorover, and supported by FAPESP (Brasil). It was originally presented as a poster at the PAIDEIA – XXth World Congress of Philosophy, in Boston/Massachusetts, august 1998.

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