The Human Brain “Projects” upon the World, Simplifying Principles and Rules for Perception

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Abstract “Each subject lives in a world where there is only of subjective realities and where the same environments represent only subjective realities.” Von Uexküll.[1]

1 Introduction: The Concept of Umwelt

“All the features of objects are in fact nothing else than the perceptive characters which are attributed to them by the subject with whom they have a relation.” This statement by von Uexküll[2] summarizes one of his essential ideas, but an even more interesting and modern thought was what he called the “lived world,” which translates into French as “monde vécu” by a subject who acts in this world. This reversal of the classical description of the mechanisms of perception and action places the intentional and goal-oriented subject at the origin of the process. The subject builds his world according to his basic needs and action tools. This view has also been promoted by Bergson and Husserl. I have also proposed that the “projective brain” is a simulator and an emulator of reality that builds its perceived world according to its planned acts and also that this new view is essential for understanding intersubjectivity (Berthoz 1997; Berthoz and Petit 2003).

The human brain imposes, in a top-down fashion, its rules of interpretation on sensory data. It transforms the perceived world according to rules of symmetry, stability, and kinematic laws derived from principles of maximum smoothness. These rules follow simplifying principles that allow the simplification of neurocomputation to speed up action. Top-down controlled attention is also a powerful selector.

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[1] J.V. Uexküll. Mondes animaux et monde humain. Denoël 1965. (The English translation is mine). p. 85.

[2] J.V. Uexküll.op. cit.

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The challenge for neuroscience today is to provide evidence concerning these speculations. I will in this presentation present some empirical data that suggest that the concept of Umwelt is applicable to man and that we are also, in a sense, prisoners of our “monde vécu.” More generally, as hypothesized by von Uexküll, the intimate resonance between action and perception is not only proven by the recent discovery of mirror neurons but also the fact that the laws of physics, like Newton’s laws, are implemented in the brain and serve as anticipatory mechanisms of action. In addition, specialized modules analyze specific properties of the environment that correspond to specific tasks such as the need to recognize the face and its emotional expressions, shape, or movement of living creatures.

Strictly speaking “Um-welt” means the “world around” in which animals and humans live. It can be translated in French by “Milieu.” However, for von Uexküll it includes the world of things in the environment, the perceived world, the signals emitted by both the subject and the things, and the actions that can be performed by each species. Above all, it includes the *significance* or meaning of things for each animal, in that they are potentially participating in the survival and social relations of the animal.

It is therefore a dynamic, interactive concept defining the relations between the physical world and living organisms, leading to *intersubjectivity*. For von Uexküll a living organism is not a machine (e.g., a watch). It is not built in a “centripetal” way by assembling parts but, on the contrary, starts from a principle, a goal, or an intentionthat, in a “centrifugal” way, determines the fitting of the parts; hence the idea that the brains of animals “project” properties on the world. They predict and anticipate. The brain does not passively receive visual information; it decides to solve ambiguities.

The brain imposes symmetry on the visual world (a beautiful example was given by psychologists in California who designed the famous Ames chambers, showing that the brain imposes symmetry on the visual world). There are many other examples of how the human brain imposes rules of interpretation upon the world and, as I proposed in my book, of the brain’s sense of “movement:” illusions are solutions in the cases where the perceived world is ambiguous. We could say in the frame of this analysis that the chosen solutions are dependent upon the Umwelt of each of us.

This view has been recently updated by theories about the way the brain predicts (Changeux 1983; Llinas 2001). Von Uexküll has also placed his theory in the perspective of evolution. He thinks that the selection of relevant information made by each species is aimed at the survival of the normal individual in the interest of the prolongation of the species itself.

2 Action Specifies the Selection of Meaningful Perception

One of the fundamental ideas contained in the concept of Umwelt is that each animal simplifies the perception of the outside world, selecting relevant information that registers with its repertoire of possible actions. In other words, the action repertoire of each species specifies the selection of meaningful, significant information that is being searched for actively. A "world" is therefore created that is made of those aspects of the environment that are important for the behavioral repertoire, or survival tools, given to each animal by evolution. Simplification is induced by this selection.

Von Uexküll writes that the bees perceive only two visual forms: open (which attracts them) or closed (which induces a flight behavior). The jackdaw does not perceive the motionless grasshopper[3]."The ground worms do not guide their action according to the form but according to the taste of the leaf. Because the sensors of the ground worm have a structure too simple to work out the perceptive characters of the form." The senses provide only one very simplified version of the objects or interesting creatures. "Only the phenomena which have a meaning for the animal subject are changed into nervous excitations."[4] (p. 124). "It is the meaning which is the leading concept with which biology must be guided, and not the poor wretched rule of causality which cannot further see more than a step ahead or a step behind, and remains blind with respect to great structural relationships ""I claim that the original partition of the fly (which one can also call his original image), its prototype, acts in such a way on the original partition of the spider that the web of the spider can be described as "flycatcher."[5]

For von Uexküll, "Each action,…, prints its signification on any neutral object and transforms it, in each world into a carrier of significance".[6] "The stem of a flower can be transformed in four different by specified environments by respectively a young girl, the ant, the larva, the cicada and the cow. It is, for each one, carrying significance because they respectively use the stem like an ornament, a road to reach the leaf, a construction material, and a food." The "form" is therefore the product of the acts of a subject. He writes: "The meaningful form, that which lasts, is always the product of a subject: it is never the product of a subject subjected to a anomic action, whatever is the duration of this action."[7]

This interpretation is extremely interesting in light of modern Neuroscience because it links very closely perception and action and actually places action at the origin of perception. The discovery of mirror neurons (Rizzolatti and Craighero 2004), which code both the action of the subject and the action of others, also calls for a repertoire of perceptions linked with the repertoire of actions of each individual. If we follow this reasoning, it could be speculated that each species may have a different repertoire of mirror neurons.

What can be the advantage of such a reduction and selection of perception? Firstly, to ensure the relevant action necessary to survival, for instance, the fact that the tick recognizes preferably Butyric acid and warm skin allows it to find the blood it needs for feeding. Secondly, it simplifies neurocomputation and allows rapid reaction to environmental hazards, prey catching or escape from predators. For

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[3] Von Uexküll op.cit. p. 73.

[4] Von Uexküll op. cit. P. 124.

[5] Von Uexküll, op.cit. p. 116.

[6] Von Uexküll op. cit. p. 100.

[7] Von Uexküll op. cit. p. 107.

example, butterflies can only detect the sounds emitted by their enemies and the rest of the world is silent; for instance, they only hear the cry of bats, which allows them to identify their predators in the complex environment that surrounds them. But it also has a more sophisticated advantage: the general understanding of the role of each object of the world in the action plan of the subject.

A well-known example given by Von Uexküll is that of the young black man who had never seen a ladder and who at first perceived it only as "sticks" and "holes." However, when he saw somebody going up, this object was suddenly perceived of as a "ladder." This example showd that we perceive objects starting not from a "mental image" but from a "potential action" done with the object (a motor schema). Von Uexküll writes: "The significance is conferred by the act of the subject"[8] (p.95). Similar ideas can be found in the phenomenological tradition in the writings of Husserl, Merleau-Ponty and in the concept of "enaction" of Varela (Varela et al. 1991). J.L. Petit and I have reviewed these ideas in our book on the relation between phenomenology and physiology of action (Berthoz and Petit 2003).

From these ideas stems the following proposal: the lived body (corps vécu) is fundamental in creating an Umwelt, even in humans. And there is no perception of the world that does not refer somehow to the acting body. This theory requires very elaborate systems of reference frames. The common house of the Mirana, the "maloca" (Karadimas 2006) is built following the architecture of two sexually defined bodies: the sky is male, the earth is female. Three spaces constitute the Umwelt of the Maloca house: the geographical space, the house, and the sexual body.

In other words, what I would like to suggest is that the selection of meaningful percepts is not only a problem of selecting sensors and stimuli. Because it is always related to some action, it also requires very sophisticated selection and manipulation of spatial reference frames. Von Uexküll had the intuition that, to simplify the problem of reference frames, it was necessary for the brain to have available a basic reference frame. He attributed to the vestibular system a fundamental role in establishing a common reference frame for perception and action.

3 The Problem of Reference Frames

For von Uexküll there is a fundamental reference frame: the vestibular system. He writes: "All the animals which have three circular semi canals also have a notion of three-dimensional space"[9] This statement was also made by Poincaré, who wrote that Japanese mice, which have only two semi-circular canals, also only have a perception of two-dimensional space!

These ideas of Poincaré and von Uexküll were very similar in that they thought that space was an active construct: "Active space is not only a space of movement made up from thousand of steps in all directions but it has a system

[8] Von Uexküll op. cit. p. 95.

[9] Von Uexküll op. cit. p. 31 and 32.

of coordinates, which is used as a basis for all the space determinations. It is of capital importance that whoever deals with the problem of space is convinced of this fact. Any normal human carries with him a frame of reference formed of three planes of the three semi-circular canals."[10] But for von Uexküll this system also allows "homing" (path integration) and more generally the memory of traveled paths.

The intuition of von Uexküll concerning the role of the vestibular system was right: it plays a fundamental role in higher cognitive processes in relation to the environment. He had an intuition about what has been recently discovered, i.e., the vestibular contribution to path integration, and more generally, to navigation. Deficits in the construction of a coherent self to which the vestibular system contributes may play a role in the symptoms of agoraphobia and spatial anxiety, autism, schizophrenia and a number of psychiatric diseases involving relations with others (empathy).

Today we know that the vestibular system is not only involved in reflex actions - such as the vestibulo-ocular reflex, which stabilizes the image of the world on the retina - or vestibule-spinal reflexes, which allow the stabilization of posture. Vestibular signals are carried through the vestibular nuclei to the sensory thalamus and from there are sent to an area called the vestibular cortex, which has been identified by fMRI studies (Bottini et al. 1994; Lobel et al. 1998; Brandt et al. 1980) to be located at the temporo-parietal junction, although other groups have located it in the posterior insula. It is now accepted that the vestibular system plays a fundamental role in spatial orientation; it is also involved in the memory of traveled paths (Berthoz et al. 1989, 1995; Israel et al. 1993, 1997a,b; Israel and Berthoz 1989; Nico et al. 2002).

However, the vestibular system is also fundamental in the elaboration of what Penfield characterized as "body awareness and spatial relationship"(Penfield 1957). Recent data from our laboratory (Kahane et al. 2003) and from other groups have shown that the stimulation of the temporo-parietal junction induced "out of body experiences," and the stimulation of areas along the peri-sylvian cortex induced a variety of illusions of rotations or elevations. It is therefore now evident that the vestibular cortex plays a fundamental role in many aspects of our relations with the outside world, and vestibular asymmetries or anomalies induce a number of perceptual deficits (Berthoz and Rousie 2001; Rousie et al. 1999). In addition the vestibular cortex seems to be involved in the elaboration of an "internal model" of Newton's law (Indovina et al. 2005; McIntyre et al. 2001; Zago and Lacquaniti 2005). It seems that, during childhood, we build a capacity to internally simulate gravity and its influence upon the movement of objects. Phrased in the terms of von Uexküll, we simulate internally a very important property of the physical world around us, which is necessary to perform our actions against the forces of gravity.

[10] Von Uexküll op.cit. p. 31.

4 Simplifying Principles Decreasing "Neurocomputation" Time and Complexity

I would like to propose the idea, implicitly contained in von Uexküll descriptions, that one of the essential reasons for the restriction of each species' Umwelt is due not only to the matching of each species' need and action repertoires but also to the need to reduce neurocomputation to achieve two main goals: speed and robustness. This, I think, is obtained through the selection, in the course of evolution, of simplifying principles that optimize the perception-action process and minimize or even suppress the "computation" needed. The simplifying principles and mechanisms used by living organisms are numerous and I will only mention a few here. The price for these simplifications is, of course, the reduction of the understanding we have about the world; it creates an Umwelt. Let me give a few examples.

Bernstein proposed that simplification was obtained for the control of movement by mechanisms of reduction of the degrees of freedom. Gibson and his followers also proposed this idea from the "ecological" theories and the concept of affordance. For example, to climb a stair the brain does not measure distances but *relations* between body size and obstacle size. The brain uses relevant variables that give it instant access to important parameters. For example, to detect moving objects the brain does not estimate distance but "time to contact" (Lee 1976). Another extremely interesting mechanism is the rapid detection of fearful shapes by the amygdala (Armony and LeDoux 1997; LaBar et al. 1998; Morris et al. 1998). The need to recognize very rapidly natural forms has also probably prompted the design of specialized areas of the brain for recognition of living creatures. Fize et al.2000 have shown that a part of the fusiform area is specialized in the rapid detection of animal faces; other areas are specialized in the detection of the body (the extrastriate body area, for instance) or even environmental forms (the parahippocampus, for instance). Although this hypothesis has not been explored so far, it can be speculated that each species has a repertoire of canonical forms that it can recognize rapidly according to the meaning of that form for each species in term of prey or predators. This ability contributes to the specification of the Umwelt of each species. Early learning during infancy probably also influences this repertoire, as shown by the ethologists for the phenomenon of "imprinting." The imprinting on the shape of the mother certainly simplifies the interaction of the baby animal with the environment.

Another important aspect of Umwelt is the nature of visual space. It is well known that each species has a different analysis of visual space and that visual perception of the world influences behavior in primates (Cheney and Seyfarth 1990). Humans may not use a Euclidian visual space; they may process visual information using affine geometry (Koenderink and van Doorn 1991) or even more complex geometries (Bijl and Koenderink 1993; Kappers et al. 1994; Koenderink and van Doorn 1991, 2000; Koenderink et al. 2002). These geometries seem complex but in fact they simplify neurocomputation

Simplification is also performed centrally by a principle of specialization of processes. A nice example is given by the fact that, in the brain, a very fast pathway identifies natural forms of animals or human forms like faces (in the fusiform area; Baker et al. 2007; Kanwisher and Yovel 2006), bodies (in the extrastriate body area; Arzy et al. 2006; Lamm and Decety 2008; Urgesi et al. 2007), environmental forms (in the parahippocmapus; Epstein et al. 1999), etc. Another important aspect of the brain's specialization that participates in the construction of our Umwelt is the mirror system (Rizzolatti 2005). Mirror neurons respond to specific gestures made either by the subject or by others, indicating that the brain contains a repertoire of predetermined gestures that are, as von Uexküll predicted, meaningful for each species.

5 Vicariousness

Von Uexküll insists upon the fact that living organisms often carry out the same action in many very different ways. (He describes the famous example of the ursin.

This flexibility of action patterns and cognitive strategies is also found in humans. Von Uexküll wrote, "The world in which an animal lives, and that we see extending around him, changes, when one looks from the point of view of the animal itself, in its environment, in the space where are acting the various carriers of meaning"[14] Humans have the ability to change points of view and escape from an egocentric view of the world.

An interesting example of this flexibility is the mechanisms of spatial memory for navigation. Mice or rats can use egocentic or allocentric strategies for navigation (Trullier et al. 1997; Burguiere et al. 2005). The human brain has a repertoire of cognitive strategies that is even more flexible (Amorim et al. 1997; Committeri et al. 2004; Galati et al. 2000; Lambrey and Berthoz 2007; Mellet et al. 2000; Schmidt et al. 2007; Vidal et al. 2004). The activity in parahippocampus and retrosplenial cortex is related to a changing point of view. The right hippocampus has become mainly specialized in allocentric coding of spatial relations and events. The left hippocampus has become specialized in sequential egocentric memory of travelled routes and episodic memory (which fits with the language description of itineraries), and this may correspond to hemispheric lateralization for spatial competences (global on the right; detailed, categorical on the left), although this point is still debated.

6 Gender Differences: are the Umwelts of Men and Women Different?

"The striking quantity and diversity of sex-related influences on brain function indicate that the still widespread assumption that sex influences are negligible cannot be justified, and probably retards progress in our field" (Cahill 2006). Gender differences are another aspect of the human, and possibly animal, Umwelt. Although this question is largely debated, it seems that men and women really do not apprehend the world in the same way. There are anatomical and neuroendocrinal bases for gender differences that are out of the scope of this paper, but it is now accepted that, whatever the origin (nature or nurture) of these differences, men and women do not process spatial information, for instance, in the same way. These gender differences are probably related, in a way that is still obscure, to the fact that large gender differences are observed in the impact of psychiatric perturbations (spatial anxiety, agoraphobia etc.) more frequently among women. For virtual navigation, women have been found to use a parieto-frontal system (ego); men use a parieto-hippocampal system. But there is no difference in navigating an eight-arm maze! Men perform better on a transfer from virtual to real space. Gender differences are also found in the use of external landmarks versus spatial representations updated by self-motion (Lambrey and Berthoz 2007). It has been suggested that spatial mental representations of large-scale environments contain more metric information in men than in women but contain more landmark information in women than in men. We found that men readily relied on an internal, egocentric representation of where landmarks were expected to be perform a pointing task, a representation that could be updated by a path integration-like process during self-motion (spatial updating). In contrast, women seemed to take their bearings more readily on the basis of the presumed stable landmarks of the external world. We suggest that this difference in spatial orientation strategy may explain why environmental representations contain more metric information in men than in women, since spatial updating necessarily requires the use of metric movement information, namely angles and distances relative to self-motion.

An interesting consequence of the differences in spatial Umwvelt is that it may also have an impact on social relations and the way we perceive others. I have proposed a theory of empathy (Berthoz 2004) that includes an important role for the capacity of the human brain to change spatial perspective.

7 The “Magic Umvelts”

Von Uexküll is interested in the fact that animals can create imaginary worlds (sometimes innate) that allow predictive behavior. He calls these “magic Umwelts:” “They are umwelts created by the subject (we would undoubtedly say today imaginary worlds or hallucinations or virtual worlds (as the dream)….that the subject itself is alone to perceive” [11]. He gives an example: the traveled path. “In the familiar path a series of perceptive signals established from memory by former experiences, take turns mutually, whereas in the innate way the same series of signals is immediately given as magic appearance….” We would probably not call this magic today, but the challenge of modern neuroscience, and of this meeting, is precisely to understand the biological basis of our Umvelt and the abilities we have to escape the innate limitations of our dialogue with the world.

[11] Von Uexküll op. cit. p. 81.

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