hortus semioticus
ISSN: 1736-3314

ON FORM, FUNCTION AND MEANING: WORKING OUT THE FOUNDATIONS OF BIOSEMIOTICS

Sara Cannizzaro
Department of Applied Social Sciences
London Metropolitan University

This paper will make a comparative discussion of the key ideas of the early 20th Century biologists Jakob von Uexküll (1864 – 1944) and D'Arcy Wentworth Thompson (1860 – 1948). These two scientists have both tackled the theme of a then popular topic of scientific interest, namely the forms of living beings.

What is interesting about their work is that both have explored the topic of form with profoundly different approaches, one focussing on the causes of form, the other focussing on the purpose of living beings' forms. However, despite this divergence of methods both of them have, sometimes to the same extent, sometimes to different extents, put forward ideas that predicted and anticipated fundamental principles in the modern disciplines of cybernetics and systems theory, and also in the more contemporary paradigm of biosemiotics. As such both Uexküll's and Thompson's work can be considered as constituting the systemic theoretical foundations of both cybernetics and biosemiotics.

Keywords: form, meaning, function, mathematics, biology


Introduction

That organic form was a popular topic at the turn of the 20th Century is evident from the excerpt below from a 1909 paper "Ant-hills: an informal investigation" by Norbert Wiener (Corresponding member no. 2073):

> The nests of different varieties of ants show interesting and instructive variations among themselves. As a matter of fact, no two ant-hills are precisely alike, either

> in structure or material. The massive heap of decayed wood forming the home of the large ants, both red and black, is incomparably different from the home of the most minute species under some protecting rock.[1]

In 1909, a 16 years old Norbert Wiener published a paper on a comparative discussion of ants-hills in a young scientists' journal named *The guide to nature* (Sleigh 2007: 163). In this short paper Wiener investigates the diversity present in different types of ant nests. The most primitive type of nest he describes is built by minute ants under a protective rock, whereas the second and more advanced type of nest consists in the building of tunnels without the protection of a rock and with the formation of little mounds of earth soil at the entrance of the tunnel. The third and most complex type of nest is the proper ant-hill, built by the large warrior ants and consisting of a pile of earth and rotten wood cemented by the ants' secretion, an opening on the outside and the self-contained overground tunnel. "All this" – Wiener concludes – "is indicative of a degree of specialized instinct if not of intelligence." However he further explains that due to the higher specialisation capability, the most advanced ants rely on slaves to build their nests and so their jaws are only fit for fighting and not for working. Therefore "The idiocy of the highly developed ant who will die of starvation in the midst of plenty is to be contrasted with the easy way in which the more primitive ants will surmount the obstacle." Wiener's interest in the correlation between ant-hills, the form of their bodily organs – the jaws – and their specialised instinct, is suggestive of an approach that closely inspects the details of organic form in order to understand where it came from and what it is for. This approach was to be developed by Wiener 40 years later with the founding of modern cybernetics.

However, in the early 20th Century and before the advent of cybernetics, Wiener's interest in the form of living beings' bodies and dwellings and in the origins and meaning of these forms was already anticipated in the 1917 work of D'Arcy Thompson and in the 1928 work of Jakob von Uexküll.

D'Arcy Wentworth Thompson

D'Arcy Wentworth Thompson (1860 – 1948) was a Scottish zoologist and was during his life both professor of biology at Dundee University and professor of natural history at St. Andrews. His interests were not only in the natural sciences, but also in Greek and Latin classic studies as well as in mathematics and physics. He is considered as the founder of biomathematics. An awareness of these interests is fundamental in order to contextualize and interpret the contributions brought about by his book *On Growth and Form* (1917 first edition, 1942 revised edition) to the fields of biology, and, as I argue, cybernetics.

In 1910 Thompson translated from the Greek Aristotle's sixth book of *Historia Animalium,* a work which was concerned with the classification and description of classes of animals, their behaviours and characteristics (this included, among shells, fishes and bird, a treatise on the differences between men and women). The influence of this translation on his later work is evident in the variety of animal

---

[1] As the subsequent quotes are taken from an internet source, that does not indicate the page numbers explicitly, only the year of publication is used here as a reference.

specimens that Thompson, as Aristotle, analyses in *On Growth and Form*. However, what Thompson did that Aristotle did not even consider, was to find a method that would allow the description of such a vast variety of natural phenomena and their differences under the common denominator of a general systems theory.

In *On Growth and Form* Thompson, in fact, envisages the need to create a theory capable of categorising a vast amount of objects (shells, teeth, insects' flights coil, tree branches' growth etc.) in terms of what these have in common, namely their shape. He also claims that the form that naturally occurs in different things can be researched despite these 'things' being dead or alive. He particularly attacks the biologist who "is deeply reluctant to compare the living with the dead, or to explain by geometry or by mechanics the things which have their part in the mystery of life" (1966 [1917]: 2). Evident here is the importance Thompson gives to a general method of description, despite the object being living or non-living. An even more salient commitment to a general, systemic theory of form and similarity is apparent when he states that "the search for differences or fundamental contrasts between the phenomena of organic and inorganic, of animate and inanimate things, has occupied many men's minds, while the search for community of principle or essential similitude has been pursued by few" (Thompson 1966 [1917]: 7). Thus, what objects have in common is more important than the ways in which they differ. Additionally, Thompson states, the problems of form are in the first instance mathematical problems (*ibid.:* 7). The reason why mathematics is, according to Thompson, an appropriate method of description is given by the fact that it can easily account for the formal similarity that a multitude of different organic objects may have in common. As he affirms:

> We are apt to think of mathematical definitions as too strict and rigid for common use, but their rigour is combined with all but endless freedom. The precise definition of an ellipse introduces us to all the ellipses of the world. [In so doing w]e discover homologies or identities which were not obvious before. (*ibid.:* 269-270)

The capability of researching homology across different types of systems is therefore what makes mathematics a suitable method for a general theory of form. Thus, Thompson believed that in order to describe "the shape of a snail-shell, the twist of a horn, the outline of a leaf, the texture of a bone, the fabric of a skeleton, the stream-lines of fish or bird, the fairy lace-work of an insect's wing [...] we must learn from the mathematician to eliminate and to discard; to keep the type in mind and leave the single case, with all its accident" (*ibid.:* 270-271). Research on a general 'type' or *system* is what will subsequently unite general systems theory, cybernetics and, I argue, biosemiotics, under the quest for a general theory of communication.

However, Thompson's principal concern was, as he declares, the study of the organism (*ibid.:* 7). Arguably the reason why he was so interested in this peculiar aspect of organisms, that is form, can be deduced from his views on evolution, as he appears to be more interested in the physical forces that shape the form of living organisms rather than heredity. For Thompson in fact, the *functional aspect* of form is far more important than blood relationships and family tree (Bonner in Thompson 1966 [1917]: xviii). Although he does not provide a preliminary definition of 'function' in his work, what is meant by this notion seems to be the access key to his thought. To define function, let us consider the following.

Thompson's central claim is that the form of an organism needs to be understood in relation to its growth. For example, the equi-angular spiral of molluscs is posited as the only way to coil and maintain the same shape as the organism grows and increases its size. Therefore form is for D'Arcy Thompson a *function of growth*. In other words, form is related to growth, subject to growth, and *dependent* on growth. Since Thompson is interested in the *changes* in organic shape, which thus must occur through time, form can be intended as *causally* depending on growth. Therefore function is here referred to as *an effect to a cause*. This is evident when he states that in order to understand "harmonious complexity", one must not only take into account teleological principles and thus only seek for ends, but also for antecedents, which is what the physicist does when he finds laws of matter and of energy in fundamental properties (Thompson1966 [1917]: 5).

The physicist's approach, in fact, is adopted by Thompson when he states that the "form apparent in movement and organisms' growth, can be described as due to the action of force" (*ibid.:* 11). Thus form is caused by growth, and growth has to do with physics' notions of process and force (*ibid.:* 13). Additionally he states that "the form of an object is a 'diagram of forces'" and "from it we can judge of or deduce the forces which are acting or have acted upon it" (*ibid.:* 11). Therefore when considering its shape an organism can be understood as a *system of causes*, because from its shape one can deduce its pattern of growth which is in turn determined by physical laws.

To identify the physical laws that affect organic shapes, Thompson identifies two variables: magnitude and 'conditions'. To understand magnitude one needs to consider the length and the weight of organisms as well as being aware that their rate of growth may differ significantly. For example, a fish doubling its length will weigh eight times more. Therefore, the proportion between length/weight can tell us whether there has been an alteration in general form or "a difference in the rate of growth in different directions" (*ibid.:* 17). Thus the scale of the organism (or the magnitude) is directly related to growth. Magnitude also has an effect on certain fundamental properties of the organism. For example, it can affect speed – the bigger the fish, the faster it tends to move; the capacity to jump – the flea jumps 200 times its own height, while the grasshopper jumps only 20-30 times its own height; and the capacity to fly – heavy birds must fly quickly, or not at all. Since magnitude determines the kind of forces that are likely to affect an organism, which in their turn directly affect the organism's shape, it appears to be a cause of organic form itself.

The 'conditions' of an organism refer to the physical forces that directly cause an organism's form. These include gravity, surface tension, viscosity and many others. For example, the forms and actions of the human body are entirely conditioned by the strength of gravity. "Were the force of gravity to be doubled our bipedal form would be a failure, and the majority of terrestrial animals would resemble short-legged saurians, or else serpents" (*ibid.:* 32). But different bodies' magnitude means that forces will affect organisms' shapes differently. Thus "the form of very small organisms is independent of gravity, and largely if not mainly, due to the force of surface tension" (*ibid.:* 36). This is the reason why, according to Thompson, while increasing volume small organisms such as the water beetle tend to assume spherical or simple forms that larger organisms do not assume. Finally, Thompson says that growth is a different process for cells, which undertake growth by division. In cells growth is limited to change of form and increase of surface, unaccompanied by growth in volume or in mass. Thus the forces acting upon cells or bacilli are not gravitation as for man, or surface tension as for the water beetle, but, among the others, the viscosity of the liquid and the resistance to the liquid in which the cells are immersed. Thus according to different magnitude or sizes of the organisms, different physical forces and conditions come into play to determine or *cause* their form, and as such they represent the main and direct cause of form.

Although Thompson avoids talking about the direct purpose of form, his argument inevitably develops into a discussion of the usefulness of organic form. This develops into a treatise on the *mechanical efficiency* of form. Thompson's argument on the efficiency of organic form is that living structures are mechanically efficient because, like engineering structures, they have to resist forces of tension and compression. These two physical forces are functions, or causes, of form and thus of its mechanical efficiency. For example, if one wants to speak of the form of a bone, one must do so firstly in relation to the mechanical properties of the material of which it is built, which is capable of withstanding forces of tension and compression to the point that the bone becomes "good for a tie as for a strut, nearly as strong to withstand rupture, or tearing asunder to resist crushing" (*ibid.:* 225). Secondly, one must consider that conditions of strain and stress exercised on the bone are a direct stimulus for its growth. Thompson states that nature strengthens the bone in the same direction in which strength is required and brings the example of the surgeon who "knows when he bandages a broken limb that he is doing more than keeping the two parts together – the pressure he applies suggests the direction of re-growth and repair for the bone" (*ibid.:* 238). Thus growth is dependent both on the capacity of organic materials to withstand conditions of forces, and to follow their direction of strain. The result of this process is the achievement of mechanical efficiency which should serve as inspiration to the human beings, especially in their attempts to build mechanically efficient structures (e.g. bridges and cranes). For example:

> The engineer, who had been busy designing a new and powerful crane, saw in a moment that the arrangement of the [fish] bony trabeculae was nothing more nor less than a diagram of the lines of stress, or directions of tensions and compression, in the loaded structure; in short, that Nature was strengthening the bone in precisely the manner and direction in which strength was required; and he is said to have cried out, "That's my crane!" (Thompson 1971: 14)

Thus, with this discussion on organic structures and mechanical efficiency, Thompson takes up a line of argument that will later become one of the standpoints of cybernetic thought: namely, the generalization from 'animal world' to 'human world'. This is particularly true in relation to the deduction of organic models from nature for the sake of solving a human engineering problem, an approach which will be later adopted in cybernetic research by Rosenblueth, Wiener and Bigelow (1943), Wiener (1951), von Neumann (1948), Bertalanffy (1968), Lovelock (1979) and Jantsch (1980).

It is with the characteristics just outlined, namely, the search for a *general method*, an interest in the characterization of *function of form* and the comparison between man-made and human-made objects that, I argue, D'Arcy Thompson's 'biomathematics' becomes an important contribution to the modern foundations of the modern discipline of cybernetics.

Jakob von Uexküll

Jakob Johann von Uexküll was an Estonian born Baltic German zoologist, who specialised in the field of muscle and neuro-physiology. From 1892 to 1903 he attended the Zoological Station of Anton Dohrn in Naples where he performed research on "the muscular movements and reflexes of sea-urchins, brittle-stars, peanut-worms and octopuses" (Rüting 2004: 3), which involved the study of the form and role of animals' organs. Interestingly enough, Jakob von Uexküll's interest in organic form did not bring about the theorisation of a general theory of form, but to the conceptualisation of a theory of meaning. One of his main concerns seemed to be the introduction of the notion of 'subject' in biology, particularly in regard to its ability to assign 'meaning' to an external world. As Rüting (2004) states, "Jakob von Uexküll (1864-1944) developed a theory of biology which decisively contradicted the mainstream of biological thought in the 20th century" (Rüting 2004: 1). In fact, Uexküll was not favourable to the mechanicist conception of living beings' forms and behaviours, since, according to him "behaviours [...] are not mechanically regulated, but meaningfully organized" (Uexküll 1982 [1940]: 26). Also, Uexküll was particularly critical of the mathematical approach to biology and in this respect, one may argue that he stood in contraposition to D'Arcy Thompson's mathematical thought. However this contraposition is a superficial one since, despite some obvious divergences, Uexküll's and Thompson's approaches reveal some similarities that can be argued to be more significant than their differences. Both of their works in fact can be argued to have led to the development of cybernetics.

Uexküll's initial characterization of his theory of meaning starts with the claim that there are no neutral objects when one living being is relating to them, only meaningful objects. This observation stems from a critique of those biologists who set themselves the task of investigating the relationship between animals and objects by, for example, experimenting on rats' limited abilities to negotiate labyrinths. The reason for such rats' failure to make their way through mazes is, according to Uexküll, that the biologists based their experiments on the false assumption that animals can enter at any time in relationship with a neutral object. Proof that this can never be the case is given by the fact that, keeping the same physical and chemical properties, the meaning of a stone changes according to *context*, e.g. it acquires 'path-quality' on a road where it supports the walker's feet, and it acquires 'throw-quality', and thus becomes a missile when it is thrown at a dog to scare him off. Therefore Uexküll states that a neutral object is transformed into a *meaning-carrier* as it enters into a relationship with a subject. The meaning of the object will be imprinted upon it by this subject. As such, there is never a way in which animals can get in touch with a 'neutral' object, since when they are in touch with an object, they always already transform it in a meaning-carrier.

Meaning is important when attempting to understand how living beings relate to objects because, according to Uexküll, meaning influences the properties of these objects when they are perceived by a subject. For example, when one inserts a domed dish in a wall and uses it as a glass window, the dish's key property becomes that of transparency because it allows one to look through it and see outside the house. When instead the domed dish is used as a vase for flowers, its key property is the one of curvature, as it then has the necessary property for containing water. The 'objective' properties of this neutral object are not altered at all during transformation, "but as soon as the glass dish has been transformed into a meaning-carrier, 'window' or 'vase', its various properties acquire a rank-order of importance" (1982 [1940]: 28). Thus, the properties of meaningful objects, although physically invariant, change order of importance. It is by providing this 'ranking' of importance for the living being that meaning influences the properties of objects.

Additionally, Uexküll argues, the more the subjects, the more meanings can be attached to the same object. It is at this point that Uexküll introduces the concept of *Umwelt*, which he cites from Werner Sombart: "no 'forest' exists as an objectively prescribed environment. There exists only a forester-, hunter-, walker-, nature-enthusiast-, wood gatherer-, berry-picker- and a fairytale-forest in which Hansel and Gretel lose their way" (Sombart in Uexküll 1982 [1940]: 29). And obviously, Uexküll adds, the meaning of the forest is multiplied if its relationship is extended from humans to animals. To qualify this thought, Uexküll gives a more detailed explanation about how the Umwelt works and brings about the example of the blooming meadow flower which comes to find itself in the Umwelt of a little girl, an ant, a cicada larva and a cow. According to the Umwelt stage in which it appears, the flower stem plays the role of ornament for the little girl, of path for the ant, of liquid extraction point for cicada-larva (which will use it to build its house) and of food for the cow. In these encounters, each component of the flower stem-object is brought into contact with a matching 'complement' in the body of the subject which will become the meaning-utilizer. Thus the Umwelt becomes the animal's personal (and thus closed) system of meaning, or its 'subjective world'. The 'resolution' of this Umwelt, as Uexküll concludes, depends on the animal's sense organs and their capacity – e.g. the girl's field of vision is wider than the ant's field of vision, which does not exceed 50cm.

By underlining the importance of sensorial perceptions in the animal's meaning-making process, Uexküll introduces us to the next core point of his theory of meaning, which is the *functional circle*. The functional circle is a way to describe the origins of behaviour in perception and reaction. Uexküll starts explaining the functional circle by stating that part of the properties of the meaning-carrier serve the subject as *perceptual cue-carriers* whereas others serve as *effector cue-carriers* (Uexküll 1982 [1940]: 31). Therefore, the colour of the blossoming flower is the little girl's perceptual cue, the ridged surface of the flower stem is the ant's perceptual cue, the smell of a suitable extraction point in the stem is the cicada's perceptual cue, whereas the taste of the flower is the cow's perceptual cue. But perceptual cues elicit a response from the perceiving subjects and thus transform into effector cues. Thus, the thinnest point in the flower stem is the girl's effector cue, or that perception that causes her to perform the action of picking up the flower; the unevenness of the stem surface is both perceptual cue for the ant's feelers, and effector cue for its feet; the liquid that comes out of the extraction point is the effector cue for the cicada since it is what will make it build the house; finally, taste is the cow's perceptual cue, but it is also what will cause the cow to take more food, so it is, additionally, an effector cue.

As shown, the action that arises out of the circular interplay between meaning-giving-animal and cue-carrier-object is what constitutes and regulates the behaviour of the living organism. "Because every behaviour begins by creating a perceptual cue and ends by printing an effector cue on the same meaning carrier, one may speak of a functional circle that connects the meaning-carrier with the subject" (Uexküll 1982 [1940]: 31). Thus the functional circle explains how behaviour originates and is regulated by what a living being perceives as relevant or eliciting a response, through its senses. Since behaviour is determined only by perceptions and reactions to those aspects of the object that are deemed relevant or meaningful for the subject, the functional circle, I argue, can be said to describe meaningful, motivated or *purposeful behaviour*. And in fact, Uexküll concludes that "the most important functional circles found in most Umwelts are the circles of physical medium, food, enemy, sex" (Uexküll 1982 [1940]: 33), which can be said to represent the motivation or purpose of behaviour.

Lastly, an important part of Uexküll's theory of meaning and the part which will allow the juxtaposition of his theory to that of Thompson, regards the role that meaning has in shaping the *form* of the organism. In other words, through his theory of meaning one may argue that Uexküll shows how form is dependent on meaning and therefore is a function of meaning. For example, when speaking of plants as subjects despite them not having a nervous system, Uexküll states that the form of a plant's organs are not determined by an environmental factor (e.g. wind) as if form was a precise effect to an objective cause, but that they are determined by a meaning factor. As he declares, "the meaningful shape [...] is always the product of a subject, and never the product of random influences on an object" (Uexküll 1982 [1940]: 37). This is because since the plant is a subject, and the wind as perceived by it becomes a meaningful object, the plant will perceive and reacts only to those properties of the wind which it will deem relevant to react to. The form that consequently the plant organs' will assume is not determined by the objective strength of the wind but by the perceptual 'judgment' that the plant will form, upon which property of the wind to react to. Generalising to include not just plants' but all animals' organs, Uexküll concludes that "the meaning of all plant and animal organs as utilizers of the meaning-factors external to them determine their shape and the distribution of their constituent matter" (Uexküll 1982 [1940]: 37). Thus the animal and its capacity to endow things with meaning is the *primary cause of its own form*, and not an objective external environment. This is a way to say, to put it simply, that living beings' behaviour is purposeful and can be studied pragmatically, i.e. in relation to their perception of the usefulness or, at least, the relevance of objects.

However as it becomes clear that the meaning-making process is responsible for the organs' form-shaping, Uexküll notes, importantly, that the meaning-command and the form-shaping command are not the same. This is because in trying to respond to the same threat, for example a predator, and thus upon endowing an external object with the same meaning of 'predator', various animals respond to it with different, rather than the same, devices. As an illustration of this fact Uexküll recalls Spemann's experiment in which he shows that two different species of short-quilled sea urchins perform the task of driving away the predator (the same goal) with different methods (different functions) (Uexküll 1982 [1940]: 48-50). One has the reflex to help it to close its pincers and poison the predator, the other one does not. However, with the differing methods available to them, the predator-meaning carrier is attacked and poisoned.

Thus similar actions (or, actions with the same purpose or endowed with the same meaning) can be carried out by similar animals which have developed differently shaped organs to confront the same situation. The point of this discussion is to get away from the mechanicist belief that since animals are subject to the same physical phenomena, they will be shaped by them in the same way; thus molluscs, for example, develop the same spiral-shaped shell in response to the same environmental conditions. Uexküll's thought marks a point of departure from this mechanicist conception because despite the 'objective' situation being the same, this does not constitute the same stimulus or does not get the same meaning assigned by the living being, who is a subject. That is why animals may develop different shapes although responding to a similar situation. Uexküll appears more concerned about underlining the degree of freedom that living beings have in respect to perceiving and reacting to their environment, rather than the degree of similarity of forms that animals acquire as a consequence of being immersed in an environment perfused with the same physical forces.

The foundations of cybernetics

A peculiar aspect of Uexküll's and Thompson's thoughts is that their works profoundly differ in certain aspects, but also interestingly overlap: they both give signs of an holistic *approach* to studying nature; they are both concerned with living beings' *form*; and they both take a stance in relation to the *function*, whether intended in terms of cause or purpose, of these forms.

(1) Holism

Holism can be an attempt to conceive of research objects not just as sums of parts that can be studied in isolation, but as systems of parts *and* their relations in which each part can be described only in relation to the other parts.

Uexküll adopts a holistic approach when he theorises the functional circle to explain the way in which organisms may end up shaping themselves upon coming in touch with their environment. In the functional circle, in fact, organs shape the kind of possible perceptions an animal may have, but perception and reaction, when envisaged in the context of an interpreting animal, in turn shape the form of the sensorial organs of the animal. This functional process ends up determining overall the animal's behaviour. In emphasising the mutually constitutive relation of organs and perceptions of the environment, the functional circle can be considered as a holistic model that conceives behaviour not as the sum of its separate parts but as the continuous interrelation between meaning-making and form-shaping commands. Also, by stating that "the living animal is more than its bodily mechanisms" (Uexküll 1982 [1940]: 41), Uexküll reminds us that the functional circle is about meaning-making *organs*, not mechanical parts, and therefore he puts forward the idea that an organism cannot be conceived of as a mechanism.

On the other hand and in a seemingly opposite fashion, Thompson envisages organic structures precisely as mechanical constructions and speaks of *parts* when describing them. However, he also specifies that

> In life the fabric of struts is surrounded and interwoven with a complicated system of ties [...]: ligament and membrane, muscle and tendon, run between bone and bone; and the beauty and strength of the mechanical construction lie not in one part or in another, but in the harmonious concatenation which all parts, soft and hard, rigid and flexible, tension-bearing and pressure-bearing, make up together. (Thompson 1961: 225)

Here, the reference to the understanding of a system as an "harmonious concatenation" of parts which are important only when considered in relation to other parts and thus as an interconnected whole, reveals the degree of holism or system thinking that is underwritten in Thompson's thought. Thus, like Uexküll's, Thompson's work is suggestive of the notion that a bodily *system* needs to be understood as more than the sum of its parts, as, at least, its parts plus the forces or relations that keep them together. In anticipating the notion of holism, they do anticipate the trend of researching systems in terms of homology, a strand of research that is consolidated by von Bertalanffy in *General System Theory* (1968).

(2) Subjective and Objective Form

An interest in organisms and particularly in the form of their living beings' body, dwellings or organs is the central theme that unites Uexküll's and Thompson's work. However the two biologists approach the topic with two different methods. D'Arcy Thompson in fact speaks of organisms and their structures as mechanisms and therefore as objects, while Uexküll speaks of living beings expressively as subjects.

D'Arcy Thompson can be said to conceive organic form as being 'objective' or object-orientated for two reasons: firstly because he is not concerned purely with describing the form of living animals or tissues, but also, and primarily, with their yet organic but non-living, bodily products such as, for example, shells or dead teeth; secondly because his characterisation of organic forms as being mechanically efficient implies that form is only a reflection of objective physical laws that affect all matter, and not a 'choice' of the living beings which is dressed by it. This would explain why, for example, a great number of molluscs have developed the same body structure in response to similar environmental situations, e.g. the spiral-shaped shell. As such, form is also a property reflected from nature that because of its objectivity can be described through mathematics.

By contrast, Uexküll's characterisation of living beings' form seems to be 'subjective' or subject-orientated. This is because by being endowed with the capability of assigning meaning to things, animals appear to possess a certain degree of freedom in developing differently shaped receptor-organs to respond to similar situations. This would explain why, for example, sea urchins have developed means to respond to the same general threat which can vastly differ in its manifestations (reflex or non-reflex organs). Thus, the characterisation of organic form as a property that comes from a subjective perception of nature explains Uexküll's deployment of a descriptive method that makes of interpretation an analytical term and that will be later recognised as being a semiotic 'method' (Sebeok 1979a, Lagerspetz 2001, Rüting 2004).

The difference between subject orientated research and object orientated research constitutes an operational paradox in cybernetic research in both its foundations and in its second-order developments. In fact whereas cyberneticians have been concerned in a similar way as Thompson with researching systems as embedded with objective properties, they have also envisaged a closed circular relation between perceptor organs and stimuli-source. This insistence on closure and on the importance of perceptor organs shows that, as Uexküll, cyberneticians have also committed to researching systems embedded with perceptual and therefore subjective knowledge. It is no surprise, then, that in 1943 Rosenblueth, Wiener and Bigelow stated that "perceiving objects should not just have capacity to perceive, but also capacity to interpret" (Bigelow 1943: 3)", thus , thus underlining the tension between researching forms that are objective and forms that are subjective.

(3) Function: Cause and Purpose

Lastly, Thompson and Uexküll are united by the fact that they have both made an effort to characterise the notion of function, although in a different and seemingly antithetical way. This is arguably a notion that they have most evidently anticipated in cybernetic research.

According to Thompson, form is a function of growth, which is itself shaped by physical laws. Although Thompson does not explain why and how growth starts or originates, he implies that because growth itself is subject to compression, tension forces (etc.), these will also be the antecedent causes of the acquisition of a particular form. Thus, in Thompson the term 'function' seems to simply exemplify a causal relationship between form and the physical force constraining and stimulating growth.

On the other hand, Uexküll's notion of function seems to imply purposeful relationship. This is because the circular exchange of perception cues and effector cues between the living being's organs and the meaning carrier-object seem to be directed toward the attainment of a goal, namely the continuous assignation of meaning. Because of its purposefulness and circularity, Uexküll's functional circle anticipates by more than a decade the cybernetic model of feedback cycle (Rüting 2004 and Lagerspetz 2001). However, because meaning is the factor continuously triggering perception and response, Uexküll's functional circle can also be seen as a continuous causality process (perception is the cause of response, which is again the cause of new perception). In the same way Thompson's physical laws as antecedent causes of form, and as causes of the mechanical efficiency of form, seem in their turn to represent a kind of purposeful goal. In short, the most evident contribution that Thompson's theory of form and Uexküll's theory of meaning anticipate in cybernetics, along with their characterisation of function, is the notion of *teleology*. This is a property of those systems that are capable of purposeful behaviour, or behaviour that is directed towards the attainment of a goal. That teleology does not exclude causality is explained by Rosenblueth, Wiener and Bigelow when they explain in "Behavior, Purpose and Teleology" (1943) that because determinism and teleology both involve a concept of causality and a time axis, teleology is not opposed to determinism but only to non-teleology (Rosenblueth, Wiener and Bigelow 1943: 4).

Thus, the comparative discussion of the similarities and differences in Thompson's and Uexküll's work has shown how they well ahead of their time incorporate the principles of homology, holism and teleology, which would come to constitute the standpoints of cybernetic research in its early modern developments. In fact, 11 years after the publication of Thompson's work, Ludwig von Bertalanffy publishes *Kritische Theorie der Formbildung* (1928, translated into English in 1933), where he outlines the fundaments of what he will later consolidate as 'General Systems Theory' (1968). Like Thompson, he stressed the importance of looking for homologies in systems of different kinds. In "The General and Logical Theory of Automata" (1948 [1963]), the mathematician von Neumann also looks for homology when he looks at living beings' capability of self-reproduction and devises a theory of self-reproducing automata. Finally in "Behavior, Purpose and Teleology" (1943), Rosenbleuth, Wiener and Bigelow officially discovered 'teleology'. As with Uexküll, they envisage living beings as teleological systems, or systems in which behaviour is regulated by purpose. This was made in the attempt to build teleological artificial systems (e.g. intelligent missiles) to be used in warfare.

D'Arcy Thompson, Jakob von Uexküll and the cyberneticians: the foundations of biosemiotics

Research on form, homology, general theory, function and purpose is not just a matter of cybernetic tradition. In his 1979 essay "Prefigurements of art" Thomas A. Sebeok explores the aesthetic forms of expression of humans and other animals in terms of what they have in common, or homologies. He does so by first categorising organic forms with the general and thus systemic nomenclature of "artistic products of averbal semiotic systems" (Sebeok 1979b: 12). These, he says, include kinaesthetic signs, musical signs, pictorial signs and architectural signs. For example, in drawing an account of research on kinaesthetic signs, Sebeok brings about a discussion on the comparison of human dance and chimpanzees' dancing in the laboratories in terms of their rhythmical structure. This homology is justified on the grounds that "it is plausible [...] to regard both underlying structures as homologous, implying that they owe their similarity to a common origin" (*ibid.:* 26) and that, thus, it can be productive to compare biological forms with cultural ones "if only to ascertain whether seemingly similar signifiers trigger comparable interpretants" (*ibid.:* 23).

In addition, Sebeok adds, the analogy between human aesthetic behaviour and animal aesthetic behaviour can throw light on "the role of *function* that rules the evolution of a behavior pattern" (Eibl-Eibesfeldt 1975 in Sebeok 1979b: 23). Thus in this framework signs, or forms, need to be considered in light of their interpretants or of their function. What Sebeok intends with the notion of function is clarified when he declares that "the ideal of semiotic analysis is to combine causal with functional explanation – to show how sign form interrelates dynamically with sign function" (*ibid.:* 13). In so doing Sebeok combines Thompson's effort to understand animals' organic forms in terms of antecedent causes, and Uexküll's effort in approaching organs' forms in terms of their place in the functional circle and thus in terms of their purposive, regulative function. Thus, the fact that Sebeok's thought is implicitly underwritten by proto-cybernetic principles should already be clear at this point. However this becomes even more evident when citing Vygotsky's claim that "apparently the possibility of releasing into art powerful passions which cannot find expression in normal everyday life is the biological basis of art" (*ibid.:* 39). Sebeok concludes that "Viewed thus, art becomes a kind of cybernetic device for keeping the organisms' milieu interiéur [...] in balance with its surroundings (milieu extérieur or Umwelt)" (*ibid.:* 39).

Sebeok is here discussing art in terms of its homeostatic sense (*ibid.:* 39). It is with this statement, this paper argues, that Sebeok draws the different research efforts of Jakob von Uexküll, D'Arcy Thompson and the first modern cyberneticians and systems thinkers such as Norbert Wiener and Ludwig von Bertalanffy under a common denominator – that of biosemiotics.

References

von Bertalanffy, L. 1968. *General System Theory. Foundations, Development, Applications*. Harmondsworth: Penguin.

Jantsch, E. 1980. *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution*. New York: Pergamon Press.

Lagerspetz, K. 2001. Jakob von Uexküll and the origins of cybernetics. *Semiotica (special issue)* 134 (1/4): 643-651.

Lovelock, J. E. 1979. *Gaia: A New Look at Life on Earth*. New York: Oxford University Press.

von Neumann, J. 1963 [1948]. The General and Logical Theory of Automata. In: Taub, A. H. (ed.) *Collected Works: John von Neumann*, vol. 5: 288-318.

Rosenbleuth, A., Wiener, N., Bigelow, J. 1943. Behavior, Purpose and Teleology. *Philosophy of Science* 10: 18-24.

Ross, W. D., and Smith, J. A. (eds.) 1910. *The works of Aristotle. Vol.4, Historia animalium*, translated by D'A.W. Thompson. Oxford: Oxford University Press.

Rüting, T. 2004. Jakob von Uexküll -Theoretical Biology, Biocybernetics and Biosemiotics. *European Communications in Mathematical and Theoretical Biology* 6: 11−16.

Sebeok, T. A. 1979a. *The Sign and its Masters*. Austin: University of Texas Press.

− 1979b. Prefigurements of Art. *Semiotica* 27: 3-73.

Sleigh, C. 2007. *Six Legs Better: A Cultural History of Myrmecology*. Baltimore and London: John Hopkins University Press.

Thompson, D'Arcy T. 1966 [1917]. *On Growth and Form*. Abridged edition. John Tyler Bonner eds. London: Cambridge University Press.

− 1971 [1917]. On Growth and Form (review). *Last Whole Earth Catalogue*, p.14.

Uexküll, J. von 1982 [1940]. The Theory of Meaning. *Semiotica* 42(1): 25-44.

Wiener, N. 1909. Ant-hills: an informal investigation. *The Guide to Nature,* Available from http://www.archive.org/stream/guidetonature02aagas/guidetonature02aagas_djvu.txt [accessed on 15/04/2010).

Tähendusest, vormist ja funktsioonist: biosemiootika aluseid välja töötades

Artiklis analüüsitakse võrdlevalt 20. sajandi alguse bioloogide Jakob von Uexkülli (1864 − 1944) ja D'Arcy Wentworth Thompsoni (1860 − 1948) põhiideesid. Mõlemad teadlased tegelesid oma aja teaduses populaarse teemaga, uurides elusolendite *vormi*. Samas tegid nad oma uurimistööd erinevatelt lähtekohtadelt — üks autoritest keskendus vormi *põhjustele*, teine aga elusolendite vormi *eesmärkidele*. Vaatamata lähenemiste lahknemisele, on nii Uexküll kui Thompson edendanud ideesid, mis ennetasid tänase küberneetika, süsteemiteooria ja ka kaasaegse biosemiootika paradigma põhimõtteid. Nii Uexkülli kui Thompsoni töid võib seega pidada süsteemiteoreetiliste aluste rajajateks nii küberneetikas kui biosemiootikas.

Märksõnad: vorm, tähendus, funktsioon, matemaatika, bioloogia.