Biosemiotics (2014) 7:1–10
DOI 10.1007/s12304-013-9191-7

ORIGINAL PAPER

From Umwelt to Soundtope: An Epistemological Essay on Cognitive Ecology

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Received: 4 January 2013 / Accepted: 15 May 2013 / Published online: 27 September 2013
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Abstract Capturing information means for every organism acquiring knowledge about the living and not living objects that exist in its surroundings. In this way, the "historical" concept of Umwelt, as a subjective surrounding has been recently integrated in the theory of landscape ecology where a landscape is not only a geographical entity but also a cognitive medium. The landscape may be considered a semiotic context used by the organisms to locate resources heterogeneously distributed in space and time. In particular, inside a landscape there are different eco-fields defined as spatial arrangements of objects carrier of meaning that organisms utilize to track resources. Along this epistemic path the sonic component of the landscape is an important carrier of information commonly used by the majority of animal species to managing many vital functions. In particular birds, which are animals with a complex system of acoustic communication, seem to organize acoustic centers for public information. These sonic patterns (soundtopes) are characterized by a great variability in space and time and function like a special eco-field that allows species to share information about the status of resources and the dynamics of populations. The availability of such public information avoids a deeper and more expensive exploration of the environment to assess its quality.

Keywords Meaningful information · Cognitive landscape · Songbird · Eco-field · Soundscape · Soundtope

Introduction

Our aim in this paper is to present an argument that the patterns and processes from which an integrated collection of segnic/cognitive relations, which is a mind-like system between organisms, emerges to guide evolutionary processes in the ecological arena. We recognise the difficulty of the theme, because to present this argument requires different epistemological, disciplinary and semantic perspectives. For this

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reason, our argument will focus on the concept of meaningful information in ecology, the exploration of the mechanisms that connect landscape and organisms and, finally, the soundtope hypothesis. This topic is submitted for discussion as an example of an emergent communicative context. It is a phenomenon that cannot only be interpreted by invoking environmental proxies, like soil composition, terrain aspect or vegetation structure, but to be correctly understood requires the elaboration of a cognitive hypothesis and the combination of different epistemologies which pass through, for example, the "communication network hypothesis" (f.i. Naguib 2005).

This narrative starts with a description of what is called the Uexküllian Umwelt which leads us to focus on the semiotic properties of the landscape, and the cognitive mechanisms needed to create a connection between individuals and their surroundings and, finally, the evolution of a diffuse "not embodied emergent mind" that acts as a context which, in some circumstances, regulates the distribution and behaviour of interacting organisms.

Historical Background

In recent years, after a long period of oblivion, the concept of Umwelt, which was used by Jacob von Uexküll (1934, 1940) to describe a subjective surrounding, is attracting the growing interest of biosemioticians (Kull 1998a, b) and ecologists (Manning et al. 2004). This renaissance is almost certainly connected to the increased visibility of biosemioticians, who are now very active, particularly in respect of theoretical issues. The growing interest in biosemiotics has been confirmed by the publication of both a scientific journal (Biosemiotics, Springer) and numerous books on the subject (e.g. Hoffmeyer 1996, 2008; Barbieri 2003, 2007). The literature on biosemiotics, as well documented by Don Favareau (2010), has long been of good quality, but its appearance has been rare, reducing the real impact of this line of thought on the scientific community.

Furthermore, and increasingly in recent decades, there has emerged from another disciplinary direction an important theory based on the patterned, energetic and informative complexity of landscapes. In particular, this theory has introduced spatiality and land heterogeneity into ecology as relevant attributes of an environment otherwise dominated by ecosystem epistemology (based on the flux of matter and energy; Odum 1971).

The birth of landscape ecology (Naveh and Lieberman 1984; Risser et al. 1984; Forman and Godron 1986), which is a fertile and popular field of basic and applied ecological research, is an important component with which to develop this narrative. This is because the landscape approach enables the link between ecology, biosemiotics and cognitive sciences to be realised (Farina 2011).

Ecology and Information

In ecology, the word information appears later in the theoretical evolution of the field, and has been connected to the concept of probability and diversity (see Margalef 1996; Ulanowicz 1997; Farina et al. 2005) in relation to which MacArthur (1957) has

been one of the pioneers by introducing the notion of diversity as an expression of complexity, rarity and evenness.

Eugene P. Odum (1971), in his classic book on general ecology, describes ecosystems as an interacting system where matter and energy are exchanged along trophic chains. No mention at all is made of information, considered only later by its brother Howard T. Odum (1983, p.19), information is in fact a common currency in the living universe and is "an intrinsic property of all organized forms of matter and energy" (Reading 2011).

Information is inside matter (structure complexity, thermic status), but is particularly located at its surface (form, colour, etc.). It is also the result of the position of objects in space (Stonier 1990). Yet information exists only if there are recipients who can receive a particular "message". In other words, it is reasonable to assume that there is both potential information and expressed information. The former could be a synonym of "intrinsic information" sensu Wiener (1948) and describes the way in which matter and energy are organised. But organisms use information to stay alive as well as to compulsorily interact with the world that exists outside the body. Such information must have a meaning, and for this reason equates to meaningful information, which Reading (2011) has defined as:

> "…a spatial or temporal pattern of organized matter or energy that is detected by an animate or manufactured receptor, which then triggers a change in the behavior, functioning, or structure of the detecting entity. The detecting entity can either be a macromolecule, a cell, an organism, a plant, an animal, or a fabricated device."

Accordingly, in our essay, we will refer to meaningful information as the basis upon which living is triggered. Capturing information means to acquire knowledge about the status of the living and non-living objects that exist outside the body. Furthermore, the more information that is acquired, the greater the probability that a recipient will survive and adapt to a changing world. So, in this respect, genetic and cultural evolution should be strictly connected to information.

Information is not a quantity, but a nominable entity (see Barbieri 2004). For instance, the information that is inside a set of vocabulary is not doubled if we have two copies thereof. This means that the mechanisms with which to receive information and transform it into knowledge are not mechanistic and quantitative, but discrete and qualitative. Definitively, semiotic mechanisms are required to acquire and manipulate information.

Landscape and Cognition

The recent development of landscape ecology as a discipline that is able to describe and manage the processes and patterns that are contained in a landscape (Urban et al. 1987; Wu and Hobbs 2002; Klink et al. 2002) is a strategic point that must be considered in our essay. The landscape has been defined in many ways according to the discipline of reference (Wiens 1992). So, a landscape is considered by geographers as a portion of land upon which people have some interest. For instance, the geographer Alexander von Humboldt has defined the landscape as the total

character of a region (Zonneveld 1995). Yet the definition used by landscape ecologists, whereby a landscape is a geographically organised space that is recognisable by specific patterns which are repeated in a similar way along a geographical dimension (Forman and Godron 1986), represents the most popular view in this field at the present time.

Recently, Farina and Napoletano (2010) defined the landscape as a semiotic interface between organisms and their surroundings, and in doing so have introduced the application of biosemiotics into the field of landscape ecology. In particular, Farina (2010, 2011) has argued that the landscape is a semiotic interface used by organisms to locate necessary resources. In other words, the landscape is considered according to this latter perspective as a source of information that derives from the shape, size and spatial arrangement of distinguished objects. These objects may be geomorphological structures, vegetation or animals. Information is required for every recipient (organism) which, to survive and reproduce, must acquire resources from its surroundings. Resources can be material, like food, immaterial, like safety, or symbolic, like sacred spots (Farina 2011).

Moreover, if cognition is the mental process of knowing, which includes aspects such as awareness, perception, reasoning, and judgment (f.i. Shettleworth 2001), the context in which cognition operates is represented by the meaningful information produced by the interpretation performed outside the "inner environment". The word "cognition" has thus been added to the term "landscape."

Information and the Cognitive Landscape

We shall now try to answer the question of what produces information and where it is located in the landscape. The landscape is per se an informative entity. Indeed, the spatial arrangement of objects and their qualities (size, shape, colour) are all informative elements from the perspective of an observing organism beyond the matter or energy that are not involved in this reasoning.

We can imagine the landscape as being precisely coincident with the informative component of the subjective surroundings, and when we use the term information we mean the presence of a recipient which, according to its nature and genetic and historical experience, captures such information and assigns it a meaning.

When we say that the landscape is the visual component of ecosystems, this is only part of the story, because other information, like the size and shape of objects, their spatial arrangement, odorous traces, and thermal or sound gradients, can be extracted by the organism. By adopting such an epistemology, the landscape assumes a central role as a source of knowledge for every organism, from bacteria to humans. To say that the landscape is an Umwelt is absolutely correct, as is the notion that we can have a "private" landscape when we refer to a single individual perspective and a "public" landscape when we deal with an informative medium that is common to a collection of organisms, such as human societies. The "public" landscape will be the culturally-fixed, shared characteristics of a (local) aggregation of individuals that functions as a filter of information. For instance, in human societies, public information creates local processes of identity, eliciting a sense of the place, a sense of belonging, architectural styles, etc.

On the basis of these premises, at least three types of landscapes have been described (Farina 2006): a Neutrality-based Landscape (NbL), where intrinsic information of the medium is not perceived by recipients which have no sensors able to capture it. The intrinsic information of this landscape can be potentially perceived after a change in the perceiving capacity (for instance, after a genetic mutation) of the recipient's sensorial skill. In conclusion, the NbL is the cradle or source from which evolutionary processes are drawn.

An Individually-based Landscape (IbL) is where intrinsic information is in part perceived by a recipient but not transformed in consequent voluntary reactions. Such information has been defined by Reading (2011) simply as "data" (patterns that are potentially meaningful). This landscape is the result of every sensorial reaction to an external stimulus.

An Observer-based Landscape (ObL) is where information is converted into a form of meaningful information by a cognitive process after being perceived by sense organs. This landscape exists when the recipient has the opportunity to assign a meaning to external signals. Such signals are transformed by a biosemiotic process into signs and, finally, into meaning. We will discuss in the next section the possible mechanisms that allow the transformation of meaningful information into an operational behaviour.

In conclusion, information as a property of matter and energy is present in the intrinsic status in every system. From this condition, information is extracted by recipients using sensorial tools, and is finally transformed by cognitive processes into a specific meaning according to the recipient's characteristics. This latter step allows species to modify the inner environment with the goal of better adapting to external novelties.

Eco-field and Biosemiotics

At this point of the narrative, after the description of the landscape as a spatial entity source of information, we intend to explore the mechanisms by which information is transformed into a meaningful form that is responsible for changes in organism behaviour. Recently, Farina and Belgrano (2004, 2006) introduced the eco-field hypothesis, which is a cognitive process that captures the information that is necessary to track specific resources.

The eco-field is defined as a spatial arrangement inside the landscape, which functions like a carrier of meaning for a specific resource. Every eco-field is associated with a cognitive template (a cued or detached representation, sensu Gardenfors 1996) that may be of genetic origin (fixed in the recipient mind) or the result of learned processes. The cognitive template is part of the "inner environment" defined by Dennett (1978, p. 79) as "any internal region that can affect and be affected by features of potential behaviour control systems".

Each cognitive template is the result of a physiological process that has its origin inside the body of an organism when a deficit of a resource occurs. Every need means that there is a shortage or deficit of a specific resource (for instance water) or context (safety, sense of place) which, to be satisfied, requires the activation of a particular function that uses a cognitive template (extracted from an inner representation). It is in this way that the physiological and cognitive circuit is completed.

At this point, we have to consider a number of different facts, the first of which is the actuality that every organism requires specific resources to stay alive, but ultimately most resources are rare and heterogeneously distributed. Then, to locate the resources required, it is necessary to optimise the energy invested in such a process in a way that the benefits must be at least equal, or superior, to the cost thereof. For this reason, the semiosis, which is the process that meets this requirement, is comprised of different steps. The first of these is the appearance of a cognitive template (a sub-set of the inner representation), which will be associated with an external eco-field. It must be made clear that it will be the cognitive template that is used to explore the surroundings until the matching eco-field is detected. For instance, green vegetation in a desert functions as an indicator of the presence of some water (the resource). So, this vegetation is the eco-field that we use when searching for the water that is not usually visible in a desert. In other words, the vegetation is our carrier of meaning (the eco-field) for water. Water will be found in the soil, below the green vegetation, and, in the same place, other resources, like nesting places, may also be present. This process can be repeated for every resource that must be extracted by the surroundings to meet the physiological requirements of an organism.

The habitat of a species can be defined as the place in which an organism finds all the resources that are necessary to stay alive and to perform the functions of living. Such a place is the ensemble of all eco-fields. Organisms gather a lot of information from the spatial arrangement of objects, like in the game of chess where the position of the pieces on the board produces information, and not simply the shape of the objects. Likewise, it is the eco-field that represents the information that is produced by the spatial arrangement of specific objects.

We consider information to be the key to the gathering of resources by using a semiotic process that is realised by an eco-field tool. This narrative could seem complex, but in reality is logical even though it is embedded in apparently different epistemologies. The cognitive process associated with the eco-field represents the bridge between information, cryptic resources and organisms.

Soundscape and Soundtopes

The soundscape, which is defined as the acoustic component of a landscape, is a mixture of different sounds produced by: 1) physical entities like running water, the blowing wind and volcano eruptions (geophonies); 2) living organisms (biophonies); and 3) the noise of human activity (anthrophonies) (Pijanowski et al. 2011).

The importance of the soundscape in animal communication is strategic to ensure the basic conditions for an efficient exchange of information between different subjects (Naguib 2005). Moreover, acoustics cues have been found to be important proxies for monitoring the effects of climatic changes on the habits of many species of animals, ranging from frogs to birds (Gibbs and Breisch 2001; Botero et al. 2009).

The quality of the soundscape is also important for human life. An environment that is too noisy can lead to health problems such as an increased risk of heart attacks, insomnia, irritability and anxiety (f.i. Moudon 2009; Gopinath et al. 2011).

In this paper, however, my focus is on the soundscape as an information container used specifically by birds to maintain intra and inter-specific acoustic contacts and to

receive and broadcast information. In fact, by using communication mechanisms (vocalisations, language, gestures, etc.), each organism shares the uniquely perceived world with all other living beings. This contributes to the formation of a collective net of eavesdropping-broadcasting relationships which are an important step along the path of the evolution of animal assemblages as an interacting complex system (Burt and Vehrencamp 2005).

Recently, Farina et al. (2011) hypothesised that, particularly during the breeding season, songbirds create a coordinated and intentionally aggregated temporal assemblage of singing individuals (a "soundtope"), which seems to function as a centre of public information (i.e. information derived from the performance of others). The soundtope becomes a highly adaptive information system that can quickly change its spatial characteristics. Indeed, it functions like a special acoustic eco-field that informs an eavesdropping individual about the status of the entire assemblage of the different species that live in an area.

Although at the moment we have little experimental evidence of the type of meaningful information that an organism can identify by hearing a soundtope, it is reasonable to hypothesise that an eavesdropping individual can recognise the variety of species, their abundance and any possible intra- and inter-specific competition events by using density, intensity and the overlap of each individual acoustic performance. In fact, there is evidence that public information facilitates the selection of a habitat for some species of birds (see f.i. the case of the eastern kingbird, *Tyrannus tyrannus*, studied by Redmond et al. 2009). Moreover, it has also been demonstrated that song rates depend on the density of birds in a particular location (McShea and Rappole 1997), and that animals use reproductive performance to assess habitat suitability (the habitat copying hypothesis) (Parejo et al. 2005).

The soundtope and vegetation seem to be quite independent of each other, which means that despite the evidence that vegetation is the major proxy for habitat selection in birds, and that its structure affects the abundance and distribution of a species (MacArthur et al. 1962), the intrinsic nature of a soundtope might depend on the temporary communication net between hetero and conspecific competitive individuals.

The soundtope thus becomes an important component of every individual Umwelt, and an investigation thereof can help us to understand the role of acoustic communication for maintaining individual fitness and, contemporarily, increasing the survival of a population and maintaining community cohesion in birds.

Conclusions

The complexity of life is linked to the necessity for organisms to replace matter and energy in their body. Furthermore, to achieve this, organisms require information that guides functions and regulates habits and behaviour. A form of autopoietic control (sensu Maturana and Varela 1980) seems to be permanently active (living status) inside organisms and, on a macro-scale, guides the relationships with a variable environment that is rich in novelties.

The information is the context that is continuously manipulated by living beings and with which animal behaviour is activated.

The perception and interpretation of the surroundings is the cognitive result of the encounter between an inner mental representation of the world and the elaboration of signals from the external world.

The perception of surroundings is essential to ensuring a living status in every organism as an evolutionary survival strategy, and this contributes to the formation of complex ecological systems.

The appearance of a superior centre (the mind) in which information is elaborated on, and from which a cognitive output is produced, has created new conditions for the evolution of life.

Separate minds are contemporarily in action in every aggregation of animals, and when they are connected to each other by a semiotic process, they create a communication-emergent web where the soundtope is an example.

Exploring the cognitive mechanisms that guide the flux of information means to enter into the biosemiotic mechanisms that convey information into specific functions.

At the end of this narrative emerges the possibility of a new ecological interpretation of environmental complexity. We have stressed that the landscape is the result of structured information coming from the characteristics of living and non-living objects and their spatial attributes. Moreover, at least three different types of landscapes are possible: NbL, IbL and ObL. The transfer of the information inside organisms thus requires interpretive (cognitive) models from the inner-world representation.

The cognitive process that is activated by the physiological deficit of a specific resource localises spatial configurations of objects (the eco-fields) in the landscape which, by adopting a semiotic process, allows the identification of associated resources to be made.

The information from the environment is represented not only by living and non-living objects, but also by communication networks like the soundtope. This object is the result of behavioural interconnections between co- and hetero-specific aggregations of interacting acoustically active individuals. The importance of this type of data is relevant in terms of energy saving because, as in the case of the soundtope just discussed, it should operate as a public centre of information and consequently avoid a deeper and more expensive exploration of the environment to assess its quality.

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