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Cognitive landscape and information: new perspectives to investigate the ecological complexity

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Abstract

Landscape ecology deals with ecological processes in their spatial context. It shares with ecosystem ecology the primate of emergent ecological disciplines. The aim of this contribution is to approach the definition of landscapes using cognitive paradigms. Neutral-based landscape (NbL), individual-based landscape (IbL) and observed-based landscape (ObL) are defined to explore the cognitive mechanisms. NbL represents the undecoded component of the cognitive matrix. The IbL is the portion of landscape perceived by the biological sensors. ObL is the part of the cognitive matrix perceived using the cultural background of the observer. The perceived landscape (PL) is composed by the sum of these three approaches of landscape perception. Two further types of information (sensu Stonier) are recognized in this process of perception: the compressed information, as it is present inside the cognitive matrix, and the decompressed information that will structure the PL when a semiotic relationship operates between the organisms and the cognitive matrix. Scaling properties of these three PL components are recognized in space and time. In NbL scale seems irrelevant, in IbL the perception is filtered by organismic scaling and in ObL the spatio-temporal scale seems of major importance. Definitively, perception is scale-dependent. A combination of the cognitive approach with information paradigms to study landscapes opens new perspectives in the interpretation of ecological complexity.

Keywords: Cognitive landscape; Neutral-based landscape; Individual-based landscape; Observer-based landscape; Cognitive matrix; Information; Scaling

1. Introduction

When for the first time Carl Troll in the 1930s coined the term landscape and recognized the importance to use aerial photographs for interpretation of the geometrical signs of the land, a new era based on ecological patterns was at the dawn. Nevertheless, the landscape paradigm suffered some decennia of oblivion due to the emerging ecosystem paradigms (Golley, 1993), reappearing in many European countries at the beginning of 1970s and only at the end of 1980s in North America, stimulated by the seminal works of Naveh and Lieberman (1984) and Forman and Godron (1986). Successively, spatial explicit models appeared an efficient

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approach for a thorough understanding of the complex dynamics of landscape processes (Wiens, 1995). Along the short but intense era of its concept, landscape has been defined in many different ways (see Farina, 1998, 2000 for a review). Landscape is considered mainly a mosaic of geographical entities in which organisms deal with the spatial arrangement of these entities determined by complex dynamics. Today a massive literature exists on this subject, focusing on a broad list of topics that ranges from disturbance processes, to relationships between animals and landscape, to shift into the application of land design and urban development (Antrop, 2001). The landscape discipline was progressively organized and today it is close to become a science branch contending the primate to the ecosystem ecology (Farina, 2004).

Ecosystem ecology and landscape ecology are two distinct perspectives to interpret the external (i.e., outside the organisms) environment. Ecosystem ecology focuses on the flow of matter and energy throughout organisms, populations and communities. Landscape ecology investigates the effect of the spatial arrangement of the objects (often denoted as patches and corridors, Forman and Godron (1986)) and related processes into a geographic realm.

Regretfully, both disciplines suffer from the lack of an epistemological framework and from the absence of intense interaction with other scientific realms. In this contribution, we present a new hypothesis on the possibility to define a novel science, and pose our curiosity in the right position at the border of the un-discovered universe. In particular, this contribution considers the landscape as an entity defined adopting a cognitive approach.

According the author's vision, a landscape should be considered a giant network of signals and signs, composed of structural and kinetic information (sensu Stonier, 1990, 1996) and modulated by the characteristics of flowing energy dynamics. The huge amount of connections define the conditions for an emerging self-organization (Ulanowicz, 1997).

To explore the possibility to characterize a science branch adopting this framework, in the full respect of the ecological heritage, we feel obliged to elaborate the links between our proper perspectives, and those already processed by other scientists that have trampled the same epistemological path (e.g., von Uexkull, 1934, 1940). We aim to explore the cognitive landscape paradigm inside the ecology realm, and for this it is necessary to consider other paradigms that interfere with the same epistemological area. Hence, we present a new approach to the long series of existing attempts to analyze and interpret landscapes, such as the biosemiotic theory (Hoffmeyer, 1997, Kull, 1998a, 1998b), meaning theory (von Uexkull, 1940), information theory (Schrodinger, 1944, Stonier, 1990, 1996); these theories are strictly linked and are useful to define a landscape ecology based on cognitive paradigms.

2. The perceived landscape

Three possibilities have been recently proposed by Farina (2004) to refine the landscape concept using a cognitive perspective. Three types of landscapes are defined: the neutral-based landscape (NbL), the individual-based landscape (IbL), and the observer-based landscape (ObL) (Fig. 1). These three definitions of landscapes have their perception, i.e. the semiotic content of the surrounding entities, in common. According to the principles of the semiotics, signals are produced by sources, and are spread in every direction. Signs are the transformation of these signals into a specific meaning. This semiotic procedure is adopted to explain the different perceived landscapes.

The NbL is the ensemble of patterns and processes that organisms do not perceive distinctively. Consequently, the NbL can be considered the un-decoded landscape (background noise), or simply but with dif-

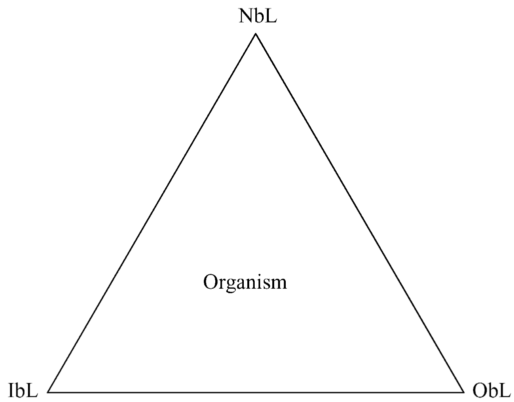

Fig. 1. Three visions of landscape when an organism is considered the vector between the real world and the perceived world. (NbL: Neutral-based Landscape, IbL: Individual-based Landscape, ObL: Observer-based Landscape).

ferent philosophical perspective, every landscape out of the organismic perception. In order to maintain a similar level of epistemological reasoning, we adopt for future argumentation the definition of NbL as the undecoded component of the signals originating from the landscape. The portion of undecoded landscape, as perceived by a species, varies according to the species trait, and can even be different within a particular species according to the living conditions. Using the von Uexkull language, the neutral landscape is not a “meaning-carrier” entity.

The IbL is the perception of the surroundings as determined by the biological sensors (smell, sight, hearing, taste, touch) by which every organism interacts with its environment. This landscape concept is consequently organism dependent. The IbL relates to the recognition of the eco-field (Farina, 1998, Farina and Belgrano, 2004) and revitalizes the concept of a subjective environment or “Umwelt”, as described by von Uexkull (1940).

The ObL is the anthropogenic way to perceive the surroundings. In this perception model, the cultural aspect enters as a supplementary component of perception, and strengthens the perception leading towards the IbL.

Culture allows to observe more profoundly the environment, and to decode and interpret both the NbL, and the IbL. For instance a person that has a cultural background in natural sciences will extract more details from the environment than an observer with an economic formation. The ObL can be considered the fraction of the total landscape de-codified by “cultural sensors”. The ObL plays a relevant role for those organisms that exhibit learning mechanisms and capacities to store their experiences into a not-genetic memory. For instance, the dance of honey bees is an example of memory and learning processes about the organism’s surroundings. The ObL has no genetic basis, which means that every new generation has to build up its own memory (cultural background) by learning. Most of our interactions with the landscape are based on this type of perception. In this way, urban, rural, forest, and riverine landscapes can be distinguished. Amenity or recreation potential become then a criterion to landscape assessment. Art, fashion, architecture, urban shape are processed components of the ObL.

The proportion of each perceived category (NbL, IbL, and ObL) varies according to the familiarity

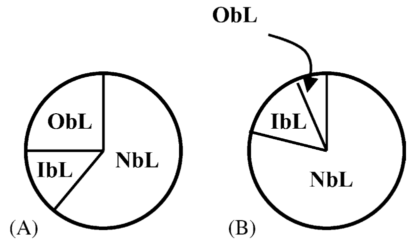

Fig. 2. Importance of the three perceived landscape categories in a familiar landscape (A) and in an unknown landscape (B) for hypothetical organisms.

by which an organism recognizes the surroundings (Fig. 2). For instance, unfamiliar surroundings expose young males of micromammals that have few possibilities to decode IbL and ObL signals in predation risk signs, to a higher risk of predation (Diffendorfer et al., 1999). At the conclusion of this description, it could be preferable to establish a further distinction of the cognitive landscape, i.e. the “perceived landscape” (PL), being the combination (sum) of NbL, IbL and ObL. This has sense only if a particular organism is referred to PL and not when the PL definition is considered the sum of all organisms, since the portions of NbL, IbL and ObL of considered organisms do not necessarily coincide.

3. Cognitive landscapes, the cognitive matrix, and information

In a cognitive landscape, two subjects interact: the organism and a cognitive matrix. When a sign is decoded from a signal, the cognitive matrix that represents the information source (memory) is operated upon. The cognitive matrix contains the “compressed” information of every organism, and every organism has a key to expand a part of such information. The earth crust and the atmosphere can be considered an abiotic matrix common to all organisms, but when entering into the life domain, the existence of an environmental (abiotic and biotic) matrix common to all has to be excluded. Every organism may (will) be part of the cognitive matrix of another organism, and likely nonlinear processes will determine the interference between PLs of different organisms.

Information has been considered as a basic property of the universe like energy and matter (Fleissner and Hofkirchner, 1996; Stonier, 1990, 1996). Information

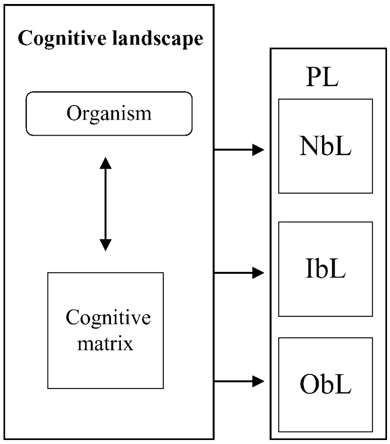

Fig. 3. The cognitive landscape is composed of the semiotic interaction between organism and the cognitive matrix (composed of compressed information). The semitoic process creates the perceived landscape (PL) that is composed of the neutral-based landscape (NbL), the individual-based landscape (IbL) and by the observer-based landscape (ObL), respectively.

refers to order, structure and organization. Every spatial arrangement is the product of structural information. Stonier (1990, 1996) distinguishes structural from kinetic information. It can be assumed, in the light of the current contribution, that at least two other categories of information can be described: the "compressed information" that exists before the coupling between the organism and the cognitive matrix, and the "expanded information" that pertains the cognitive processes and which produces the PL (splitting into NbL, IbL and ObL) (Fig. 3).

4. Scale and perception

Scale has become recently a key term in landscape ecological literature. It is even considered a conceptual breakpoint to ecology as a discipline (Mac Nally, 1999), and has led to cross-fertilization with other disciplines, such as fractal theory (e.g., Krummel et al., 1987, Imre and Bogaert, 2004). The geographical or spatial context present in landscape research (Stine and Hunsaker, 2001) has doubtless contributed to the gain of importance of scale aspects in landscape ecology, while it has already been a tradition to include scaling in plant ecology studies (e.g., Greig-Smith, 1954).

Scale generally refers to the spatio-temporal dimension in which organisms, patterns or processes are recognizable (Farina, 1998), and is defined as a particular range of spatial and temporal frequencies (Rees, 1999). This range is described by the resolution below which faster and smaller frequencies are considered "noise", and the extent above which slower and larger frequencies are "background".

Landscape ecology research is posed from a scale of a few meters (e.g., edge effects, Chen (1991)) up to a 1000 km (e.g., land cover dynamics at continental scale, Bogaert et al. (2002)), across which most ecological processes are completed (Farina, 1998). Because landscapes themselves are spatially heterogeneous entities, their structure, function and dynamics are scale-dependent. Domains of scale appear to exist in which a relationship established at a particular scale may be reliably extrapolated at similar scales, but may break down when applied at very different scales (Krummel et al., 1987, Gustafson, 1998). In fact, moving across ecological processes, abiotic and biotic interactions have families of scales, which exhibit emerging properties (Farina, 1998). The most appropriate scale to investigate (or observe, perceive) a pattern or process is the one that can allow us to collect most of information. The appropriate spatio-temporal scales can be determined by geostatistical analysis (Fortin, 1999), especially when system properties vary gradually in space and/or time (Gustafson, 1998). It is helpful to distinguish two types of scales. The observation or perception scale as the one used to measure a process or pattern on one hand, and the process or pattern scale exhibited by natural phenomena (e.g., the landscape signals) on the other hand. This latter type is independent of the observer's control (Farina, 1998), and is also denoted as the "inherent scale". The scale of (landscape) perception is determined by its two components grain and extent. Grain can be defined as the lower limit of what can be perceived, and refers to the absolute strength of the signals, and the specificity of the different signals (defined as the ability to discriminate two different signals in space or time). The extent is equivalent to the spatio-temporal range to which signals can be perceived. Detection of scales will be individually based, since dependent on the signal sensors, which will contribute to the ultimate signal-sign conversion. Species show however, the capacity to change the scale of observation: their perception of the envi-

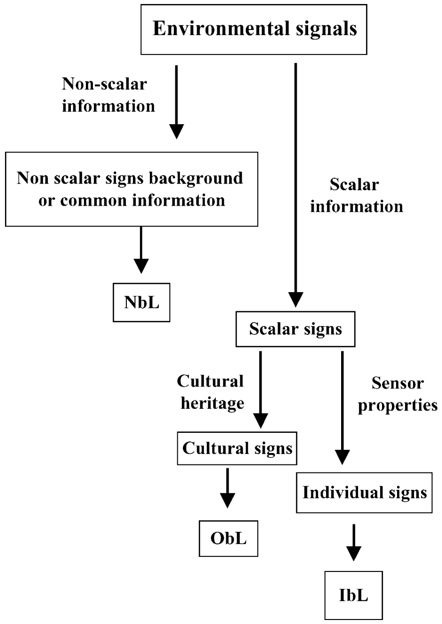

Fig. 4. The relationship between scalar properties and cognitive landscapes.

ronment (i.e., their landscape definition) can change by processes such as dormancy or dispersion, or is varied with seasonal or internal rhythms (Farina, 1998).

Application of the scale concept (Fig. 4) on cognitive perception of landscapes is appealing. The NbL is likely to represent a scale-independent landscape, since not perceived distinctly by organisms. It exists anyhow, and represents non-scalar "background" information, which requires the absence of scalar variability. The IbL groups the signals and their concomitant signs from the surroundings filtered by the scaling properties of the individual's sensors: the perception scale hence selects certain signals and determines the final sign set for interpretation. This sign set corresponds hence with the aforementioned "Umwelt" and "ecofield" concepts. While the perception scale filters or reduces the signs obtained and defines the IbL, the cultural background of the observer "enriches" the perceived environment, since signal transformation is influenced by cultural heritage or past learning processes. This factor has doubtless multiscalar spatio-temporal properties. The observer's knowledge (i.e., everything the observer has learned and experienced, definable as culture s.l.) is characterized by different degrees of detail and comprehensiveness, which will interact with time lags and periods, and is dependent on the spatial framework. For example, the knowledge (or memory) is the most advanced or detailed regarding the observer's proper life, in his/hers home country, and concerning recent events. If time passes between an event and the moment of recollection, the precision of the information will generally decrease, and even entire packages of information will be lost (e.g., recollection of childhood becomes vague and discontinuous). Knowledge regarding the observer's proper life is more complete that information about the life of a friend or relative. More detailed information is stored in the observer's mind in his/her home town (e.g., street names and locations, landmarks), while for cities that have been visited abroad for a shorter time, generally mere a general impression remains, only based on key features. When the scale of perception is changed, e.g., by visiting the city again, by talking to a relative or friend about his/hers life, or by looking at pictures of the childhood, the information in the observer's memory is refreshed, updated and completed. These examples demonstrate the scale-dependence of perception, and illustrate that the application of the scale concept discriminates NbL from of ObL and IbL.

5. Conclusions

The paradigmatic model of the cognitive landscape introduces a new field of research that we can call "Cognitive Landscape Ecology". The cognition as an information decompressing mechanism is common to all organisms, also to those, like plants and procariotes, that have not an advanced nervous system to perform perception, but that are able to perceive their surroundings by chemical processes. Cognition operates at all geographical and temporal scales from the level of the "leaf landscape" being the butterfly caterpillar "Umwelt", to the level of river-inland vegetational ecotones.

The cognitive approach opens the road to other important issues operating in the landscape arena like the landscape ontogenesis and the eco-field paradigm (Farina, 2004, Farina and Belgrano, 2004). The cognitive approach connects also information theory to semiosis and allows to reconsider the entire history of landscape ecology that suffers from the continuos pairing with the epistemological approach of ecosystem ecology. The vision of a new dimension realized by the integration between information and cognition represents an exciting inspiration for modeling, empirical field research, and application of new metrics (Cropley, 1998a, 1998b). Since ecological complexity cannot be explained by using mechanistic paradigms, the integration between cognition and information represents one of the new frontiers in ecological research.

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