American Journal of Psychology and Behavioral Sciences
2018; 5(2): 23-33
http://www.openscienceonline.com/journal/ajpbs
ISSN: 2381-5957 (Print); ISSN: 2381-5965 (Online)

Open Science

Cognitive Aspects of Soundscape Acknowledgment Using a Virtual Reality (VR) Tool

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To cite this article

Philippe Woloszyn. Cognitive Aspects of Soundscape Acknowledgment Using a Virtual Reality (VR) Tool. *American Journal of Psychology and Behavioral Sciences.* Vol. 5, No. 2, 2018, pp. 23-33.

Received: March 25, 2018; **Accepted**: April 15, 2018; **Published**: June 5, 2018

Abstract

Within the *World Soundscape Project*, Robert Murray Schäfer the *Soundscape* concept, inducing the capacity to restitute identity to the sonic environment through organizing its constitutive elements. Articulated to its social representations, construction of the perceived soundscape reveals a sonic identity structure, which is evaluable through its ambience cognitive structure characterization. To experiment this characterization principle, an immersive and interactive device, the *Urban Participative HyperAmbiantopes* (HAUP), is presented, thus allowing soundscapes reconstruction by using an hypertextual navigation mode within an immersive spherical view of the city. Soundscape reconstruction shares listening action between the two modalities of actual perception and imaginary reconstruction, implying a twin holistic and systemic codification mode of urban soundscape events. Soundscape can therefore be described as a combination of the previous sound sources, belonging to specified hierarchical meta-classes. Thereafter, hetero-chronical evolution of sound ambience acknowledgement enables sound identity reconstruction using virtual reality systems.

Keywords

Hyper Ambiantope, Image-Schema, Soundscape, Metaphorical Projection, Virtual Reality, Ideoscenes

1. Introduction

The question of space and its individual and social representations is a crucial aspect of the problem of sustainable human development. Indeed, it is in a context of permanently mutating space that the ability to make society is questioned through the social appropriation of environment quality and sustainable co-management of living spaces. In order to develop analytical skills to interrogate the socio-environmental strategies of daily territories appropriation, we consider user values of public spaces as a transfiguration of reality in the field of landscape experience.

The landscape experience, by creating a "connivance" relationship with the studied environment [1], enables geographical approaches to bring out the "cultural depth" of its expression, including the landscape in the semantic and conceptual set of the socio- ecological "living-perceived space" paradigm [2]. Within the interdisciplinary move between the borders of social sciences, nature sciences, physical sciences and aesthetics [3], this paradigmatic view of the landscape can be transformed into a multimodal and open exploration system of our entropized natures, the cities. It is thus possible to observe the interactions between explorers - also actors of the urban space - and the landscape system, to analyze their points of view and mental representations, that is, to observe their "connivance" with the perceived land- or soundscape.

This approach makes it possible to model the shared perception of landscapes in terms of an open system integrating several dimensions:

1. the physical laws of environment interaction,
2. the psychophysiological data of ambience perception,
3. the sociospatial rules of behavior in urban environment.

Those inter-articulated dimensions should be revealed through targeted observations or dedicated inquiries (interview, participatory survey, qualitative discourse analysis and quantitative analysis of ambient indicators, here sound sources). The quantitative descriptors resulting from those perceived soundscapes analysis are then structured by

encoding sound information as a landscape element occurrence, in our case, a sound source within the urban ambient maze [4].

2. Perception, Information, Cognition, a Flash Review

To clarify this transversal research field, exposition and critical analysis of major theories of perception is presented thereafter. As perception studies is a complex, blurred-marked multidisciplinary field, this state of the art has no pretention to be exhaustive, as the different disciplines presented here have been chosen for their relevance within cognitive science research actuality.

2.1. From Psychology to Psychophysics

From a psychological point of view, "perception covers all the procedures that allow us to learn about the surrounding world and to build our own mental representations of this world" [5]. In this way, perceiving is a permanent action, based on complex, not automated, mechanisms. Thus, perception of an object is stimulated by energy coming not from the object itself, but from stimulation acts performing on different sensorial systems such as sight, hearing, smelling. Treated either from a perspective of behavioral ecological psychology [6], [7], or in those of a phenomenological psychoanthropology [8], [9], perception skills based on environmental instrumentation is thus proposed by the affordance theory to propose a prospective dimension to perception [10]. As affordances are considered both external and within the perceiver, they define a dialogical relationship between environmental events and perceiver's needs or values. Thus, affordance concept is considered as essential for understanding perceptual-motor development [11].

Rather than mere psychological doctrine, Gestalt theory was conceived as a general theory of form and organization. [12]. In Gestalt theory, perceptual grouping and figure–ground organization respond to principle of global recognition by discontinuous stimulus [13], [14]. Thus, figure–ground perception characterizes objects under a unitary appearance, apprehended as a whole and not as a sum of their parts. Within actual scientific developments, mainly vision-recognition sciences, conceptual and theoretical foundations of the Gestalt approach remain the principal theoretical background to treat perception trends [15].

Moreover, cognitive psychology explain perception as "the result of all of mental operations allowing to give a meaning to the sensory inputs" ([5], p. 11). Thus, information processing is directly related to the stimulus characteristics. Information treatment can therefore be achieved at several levels: directly from the stimulus or cognitively controlled in relationship with cognitive patterns, acting in terms of multidimensional interpretations. As an example, artificial intelligence considers perception "as a set of specific procedures for solving problems" ([5], p. 13).

According to psychophysics theory [16], perception provides environmental information that emphasizes the role of the stimulus treating and encoding information, thus leading to representation construction. Beyond usual consideration of the action of the physical environment on man, produced psychological effects are generally evaluated by stimulus/response experiments. By identifying the relevant parameters through quantization experiments, it is possible to approach the interface between physical value and perceived intensity, with characterizing a dual action of environment on man and man on environment [17]. Therefore, psychophysics proposes mathematical functions connecting the physical characterization of the stimulus to the corresponding sensation perceived by the subject, i.e. Weber-Fechner law, described in [18], assuming that both visual acuity and sound perceived intensity are proportional to the logarithm of the intensity of their respective stimulus. This approach is therefore strictly relevant of the basic recognition or identification of environmental components [19]. As recognition and symbolic information treatment attest the subject's participation in the construction of the interactional emergence, it's important to take the prior environmental representations that contribute to the perceptual act into account.

2.2. The Environmental Transactions Challenge

Part of many schools of thought suggesting an intelligence of perception shows that the behaviors of individuals can be deduced from stimuli objects they imply. Stating that we perceive the shapes and material properties of objects quickly and reliably despite the complexity and objective ambiguities of natural images, this theory states that we imply neural mechanisms to organize objects perception. Moreover, Bayesian theories of perception shows that complexity may be managed through probabilistic integration of prior object knowledge [20]. Above all, probabilistic functionalism showed that the perception was not solely defined by sensory message, but was influenced by factors related to experience, emotions, values [21]. The stimulation conveys information processing, the selection of which depending on the above factors, thus attributing a predictive value to perceived objects. This is part of an hypothetico-deductive approach where assumptions about the nature of objects will be partially or totally infirmed or confirmed by stimulation-conveyed information. In this field of quantitative statistical approach of cognitive systems organization, [22] develops a hypothetical nervous system called "perceptron", thus bridging biophysics and psychology. This theory constitutes one of the origins of neural network modeling.

As human behavior depends on the ambient situation in which he lives, environmental psychology pay particular attention to the interaction mechanism between man and environment. Thus, this discipline functions following inductive skills, adding an important dimension to psychology through describing behavior or perception gaps due to contextual variables of environment. As here, well-being is

understood as life cycle and temporal horizon of the individual, spatial appropriation and cultural heritage develops individual and social identity, under the timeline of historical dimension [23]. Thus, environmental psychology adds to psychophysical determinism the double paradigm of interactional and transactional perspective, with treating interaction between individuals and physico-social environments in their spatiotemporal dimensions. Dedicated analysis thus implies a systemic interrelationship conceptualization, as environmental physical and social factors are inextricably joined within individual behavior and perception [24].

2.3. From Spatial Structures to Temporal Systems

Following structural approaches [25], [26], information structure is considered as communication organized atoms – signs- transiting through a specified spatial and temporal channel, summing objects on the "present thickness", the whole conveyed message being organized in a temporal sequence. This transformation of the physical reality to the mental act of perception requires specific incremental thresholds in the areas of spatial, temporal and frequency domains of the perceived phenomenon. Indeed, this "present thickness" involves the physical phenomenon-specific integration time itself, as it can also depend on the availability of the subject's reception. The amount of information involved in the reception system is here directly related to the accommodation principle during the interaction process: this defines the notion of "psychophysical impedance" between the subject and his environment [17].

Within information theory, perception encoding adds another complexity layer in the formalization of the environment perceived elements, as the message is not transmitted globally, but in the form of a tree of messages, sub-messages, etc. These "nested levels of perception", also called "super-signs" [6], optimize the encoding of the message for transmission through the principle of optimal coding, [27], associated to multiscale quantization based on the principle of the least effort [28]. Therefore, the perception information architecture is hierarchically coding signs and super-signs to specified levels, following a hierarchy of remarkable perceived elements, which measure is using specific metrics based on ordinal and cardinal statistics. Thus, to understand perception as a link in the information transmission chain between man and environment, it seems essential to use two homomorphic metrics, which may describe the same formal structure of perception. This approach, close to ecological psychology [19], and more generally, to structuralism [25], defines the concept of interactional emergence, allowing an associative analysis of its elements, which can be treated using the information theory tools, through associating quantization and classification principles [29], [30].

2.4. An Evolutionary Perspective

At last, complex systems dynamics approach applied to the cognitive sciences like the ecologist's well-known "viability theory", [31] develops an evolutionary conception of perception, thus considered as a time-structured interaction system.

Viability theory designs and develops mathematical and algorithmic methods to investigate the adaptation to viability constraints of evolutions governed by complex systems under uncertainty that are found in many domains, namely in cognitive sciences [32]. This theory argues that perception is driven by a regulation procedure called "cognitive regulon", which increases the viability of the interactional system. It therefore constitutes an objective indicator of perception dynamics, as the regulon temporal regime is a descriptor of the perception system stability. Thereby, the working hypothesis developed in the present research states that sound identity of a territory can be assessed on the basis of a characterization strategy of the cognitive structure of perceived ambiances. In that way, it's the multimodal structure of the urban multi-sensorial experience that defines the construction mode of the "acoustic landscape"- the soundscape- in an urban situation. This conception, according to which the mind of man functions essentially by association, is supported by the previously presented concepts relative to cognitive and environmental psychology, information theory and viability theory, namely image-schemas [33], teleological assumptions [34] and evolutionary systems [35], [31]. In this respect, making the virtual reality explorer construct and structure its own domain of ambient knowledge seems a major cognitive specificity of perception.

3. Specificities of Virtual Reality Soundscape Reconstruction

Generally, immersive virtual restitution of a land- or soundscape is used as a starting point for a virtual visit of the environment, in the flow of which a set of articulated documents viewable in a non-linear manner can then be generated. This constitutes the documentary structure we applied in the referent interactive virtual system into which the soundwalker is immerged, a so-called "acoustic hyper-scape".

3.1. Hyper-Navigation Facilities in VR Systems

Interactive documentation within a virtual visit takes the form of a hypertext structure, which performs jumps from one fragment of the document to another. Like a Brownian motion, it constructs and deconstructs recursive networks and nested information units, in a discontinuous temporality. This hypertextual division of information is formalized by nodes connected with links, thus offering the possibility to design documents by associative networks, according to their semantic or even aesthetic proximity. Technically, virtual reality (VR) systems involve both multimodality and hyper-textuality to associate a scheme or an image, text elements or a picture, a sound, a filmic sequence within the projected

landscape. It is this multimodality and hyper-textuality mix which constitute the hypermedia structure of territorial information available in this kind of reproduction. Thus, documentary hyper-mediation involves information interconnecting networks through links that can be activated by the user via "hyperwords" for a literary frame or "hyperobjects" for a multimedia frame. Hypermedia structures are then characterized by the association of the specificities of both hypertext and multimedia document structure, hyper-media, with structuring fixed or animated images, sounds, or textual supports.

A hypertext/media document is therefore reachable through a process of hyper-textual "navigation", with using exploration tool shaped from mind mapping structures and associative strategies. Generally designed on a combinatorial architecture basis, multiple choice property of hyperdocument allows the construction of an original itinerary by the explorer.

The multiplicity of possible reading itineraries of hyper-organized information, formalized with the reticular nodes-links structure, organizes a complex information network. This therefore involves a nonlinear scenario of information discovery based on field observations and consultation materials, thanks to the semantic links that can be activated in navigation supports. Intentional bifurcations at each stage of the document structure implies a particular involvement of the explorer, the soundwalker in our case, in the multimedia structure of the document, within the virtual reality immersion system.

3.2. Territorial Information as a Perception Dataset Structure

The double property of non-linearity and associativity allows the hyper-scape to propose a multi-scale dimensioning of territorial information. Fragmentary consultation of a hyper-scape document also supposes the creation of new sensorimotor and vision-spatial landmarks informing the user about its localization and displacement within the territorial information map. This is particularly important during multimedia navigation process, where immersion monopolizes much of the user's attention and where the loss of the markers can be faster than in a "classical" navigation, i.e. within a literacy document.

Cognitive ergonomics, with taking the form of rules or guidance instruments, should assist the user in managing the navigation tasks within the hyperdocument. Indeed, the semiotic specificities of hyperscapes -associativity, non-linearity and immersion- result in the creation of particular cognitive effects tools, in order to make cognitive information available within the navigation interface user [36].

Thus, richness and complexity of hyper-scape depends on the way in which it is perceived, experienced, analyzed and interpreted by the author, according to his individual or collective positioning, his prior knowledge, objectives, and even its civic engagement (eco-responsibility for example). Therefore, reinterpretation of the landscape documentary content by the explorer highlights the relations between the constituent elements of the environment and his centers of interest.

3.3. The Soundwalker Worldline within Urban Ambiences

For the pedestrian who circulates in the urban landscape, the ambient phenomenon superposed to the urban space can be considered as a marker of this space [37]. This landscape reveals ambient phenomena that punctuate space along the wander direction, following the so-called "worldline" of the man in the city. While retaining the idea of a perceptual continuum during the journey, the "worldline" constitutes an analogical reading of a time-line interaction in the urban maze, allowing to conceptualize sensory propagation in action in the perceived environment, through informing the emergence conditions of remarkable elements during his navigation. The fundamental principle of world-line claims that an observer both identify the beginning and the end of a perceived event. This assumption states that the observer codes its corresponding time-segment as a causal attribute of the perceived land- or soundscapes. In our case, for a given subject and within a given observation period, soundscape knowledge of an observer is relevant to sound sources emergence and occurrence frequencies. Those two subjective characteristics constitute the main scaling dimensions which have to be defined for informational quantization, entropy, which value describes the uncertainty quantity of the concerned source. Involved emergence and occurrence frequencies are based on empirical sound sources frequencies measurement issued from observation statistics from inquiries and soundwalkers expressions, related to the perceived soundscape.

Instrumental exploration of these composition terms is thus approached by a hyperlink restitution protocol applied to sound, within the virtual landscape consultation. This last allows to translate the multiplicity of information levels to be taken into account in order to reveal the necessary perspectivism to apprehend environmental perception.

Hypermedia instrumentation of landscape immersion will also allow the sound explorer to question the soundscapes of an urban scene in the present situation, past reconstitution or future projection. As part of soundscape studies, sonic transcription of reality is intended to identify the emergence of sound knowledge of territorial identities, the "sonotopes" [38]. Through the analysis of the successive manipulations of their daily soundscape, this system then allows listeners to access to their sound representations, following their worldline temporality.

This approach has been applied in the development of a multimedia cooperative tool, through the use of advanced technological resources in terms of hypermedia representation, within interactive navigation, in order to allow co-production and co-management of territorial information. This way of describing a landscape, or of writing a hyper-scape proposed in the HAUP interface described thereafter, is thus able to formalize, describe and

transcribe complex concepts and objects related to the sound environment by generating a specific node-links network architecture during the listener's navigation.

4. From Sound Events to Background Noise: The HAUP Immersive Worldline Experiment

4.1. A Soundscape Mediation System

The HAUP "*HyperAmbiotopes Urbains Participatifs*" project is a scientific mediation system using an spatialized multimedia instrumentation of the soundscape to reconstitute the immersive sound ambience of the cities, in order to gather a reading grid of the territories.

Situated inside a spherical projection system, the user is prompted to place sounds in the surrounding sphere of the panoramic image of the urban space, associated with a spatialized sound diffusion system. This sound manipulation is operated *via* a touchpad, thus permitting a hypermedia navigation within the immersive re-constructed soundscape [39]. After having recorded soundscapes in respect to their spatial components, a multisource analysis makes it possible to discriminate the sources families composing the resulting sound scene, following three categories of sonic objects: events, textures, and backgrounds, with allowing their manipulation in hypermedia navigation mode.

Constituting a *continuum* from emergent elements of the soundscene, this reproduction system polarizes the operator's attention to most distant diffuse background. The corresponding sonotopes are then hierarchized to reconstruct the sensory perspective of the urban soundscape within the VR immersive device.

4.2. From Soundmarks to Keynotes

From a holistic point of view, the morphology of a soundscape is constituted by the territorializing and the temporalization of the different information levels of its sources. The "near order perception mode" constitute the foreground of the landscape scene, the sound events. On the other side, time structural homogeneity of sound reveals the sonic "background" of the perceived scene, the *Keynote*, according to [40], which involves the listener in a "far order perception mode". Between those two perception modes orders, sound textures may act as a structuring element with variable emergence possibilities.

Events bearing the identity of the place, also called "Soundmarks" by [40], relevant of "near-order" sound sources, are constituted from isolated sound manifestations, well discriminated in space and in time. Nearest order sources are constituted by emergent signals such as bells or alerts. Inspired by the work of [40] and [41], near-order sound events perceptual typology adopted in HAUP project [42], distinguishes people (discussions, walking steps,...), vehicles (buses, cars, mopeds,...) and signals (sirens, ambulances,...). These events are of two types: static ones with permanent localization in the scene, and dynamic ones which are describing a trajectory in the scene.

Moreover, through polarizing the soundscape, textures are structuring elements of the sonotope, providing presence and stability in the sound range [17]. Constituted by a set of events, which, because of their density and distance, are no longer perceived as individual sources, sound textures are revealers of the sound identity of a place. It is a set that colors the environment (discussions, rain, birds,...). Finally, when the information quantity of a texture reaches saturation, the latter then switches to background noise. Thus, sound textures are the more plastic sound element, as their entropy levels should vary in a large scale, in function of their emergence potential. Two categories of texture are proposed in this device. Clusters, making up a set of similar sound elements (voices, birds) that emerge and disappear respectively at the same point of space, and wakes, defining a set of sound elements that follow the same trajectory without moving at the same speed, thus creating a sound "trail". There are permanent wakes, such as a roadway or a pedestrian trajectory, as opposed to limited ones, as can be a flight of birds for example. Wakes are defined by trajectories, directions, average displacement velocities and length. Situated on the opposite scale of the sound events order spectrum, "far order" rumor, or "Keynote" [40], describes indistinct background noise, diffuse acoustic atmosphere constituted by slow-modulating sound signals (so-called "band-noise", as for distant circulation, electric hum, calm,...). It is thus difficult to determine the source of this rumor, as it is perceived as omnipresent and nevertheless endowed with an important identity charge. The listener's ear will not be deceived when it comes to discern between the rumor of a street in New York or Napoli, each soundscape being signed with a specific timbre or rhythmic. Note that technically, rumors surrounding sound is recorded using a microphone with tetrahedral capsules (Soundfield® type microphone), allowing to restitute the city sound spatialisation of every component source.

This statistical evaluation of the rate of occurrence of a sound source or of a group of sources allows us to develop a typology constituting the sound landscape, using an *ad-hoc* classification method, which distance position within the order spectrum is defined by an autocorrelation statistical measure of their order spectrum, quantified by the corresponding entropy level.

4.3. Sources Hierarchy and Entropy Measurement

For a done subject, and within a done observation period, soundscape acknowledgement is relevant to sound sources emergence and occurrence frequency. It is thus a matter here of deconstructing-reconstructing the common landscape representations, which have the property of being systematically located at one or the other end of the chain of man-environment communication. As such, landscape is treated as a physical, living and natural being, to be cut ("anatomized"), zoned ("atomized") and quantified

("entropized"), to define this new space in which the interaction unfolds. Teleological dimensioning of the event structure perception should then be evaluated by entropy measurement.

In order to evaluate the sound environment gradient in its continuum, the notion of entropy is centered on the theories of information that [27] have introduced. Within this work of Claude Shannon and Norbert Wiener published in the Bell System Technical Journal in 1948, entropy introduce the mathematical definitions of the information quantity. Moreover, the definition of entropy by Shannon is constructed from the discrete case by quantifying a sequence of symbols, whereas that of Wiener is rather in a continuous logic, studying the variation of a signal. Through its synthesis of engineering disciplines, these definitions are based on a major conceptual innovation, the use of probabilities. By building bridges between statistical physics, engineering sciences, life sciences and cognition sciences, the notion of entropy allowed the transfer of the notion of information through all these disciplinary fields.

This theory refers to the temporal and spatial characteristics of the transmission channel, namely the urban structure. In order to evaluate both reception and perception performance, entropy quantifies the interactional emergence within an environment, together with the organized sound material [43]. Those lasts constitute two key notions for understanding perception as a link in the information transmission chain. Entropy, as a measure of uncertainty of perceived sound events, constitutes an approach of the soundscape originality, or the ability of its components to focus the listener [37]. Within this approach, entropy measure of a soundscape can be provided by both frequency statistics and emergence probabilities of the observed main soundscape events. Because a soundscape sources composition is necessarily dispersed over time, the use of aggregation in entropy indexing specifically addresses the issue of temporal reliability. Therefore, brief moments of soundscape observation has to be repeated over different periods (morning-afternoon, day-night, or seasonally), to ensure this information quantization. Temporal stability can then be appreciated through dispersion calculation of relevant entropy indices, so that the "informational portrait" of the soundscape can be defined over a sufficient number of observations.

A soundwalk event distribution can therefore be approached through its uncertainty evaluation with both local and global entropy indexing, related to a subjective territorial interaction. Nevertheless, as expression of soundscape entropy is relevant to the soundwalker experiential knowledge, this indicator remains fundamentally subjective. Moreover, this quantity helps to study the behavior of the acoustical information taking into account the sound sources composing the studied soundscape. Entropy level gives us the extension value of the corresponding sound event, the "soundmark" according to [40], considering its ability to reach the listener during the corresponding urban soundwalk. Entropy quantization of heard sound sources then define all the relative distances between the pedestrian sensor and the perceived landscape acoustic objects.

Nevertheless, this "distal evaluation" of the two ends of the landscape communication chain is articulated to two reference spaces at the basis of the landscape interaction. Indeed, hyperscape consultation mode involves both the Cartesian metric space, situating all physical attributes (objectives or object) of the environment, and the anthropocentric space, corresponding to the metaphorical projection action, the "bubble" or "shell" of the perceiving subject, on the wall of which are projected the sensitive translations of the phenomenal manifestations of surrounding soundscape objects.

4.4. The Soundscape Real and Imaginary Dimensions

In VR urban reproduction systems, emergence of land- and sound sources is conditioned by descriptive variables, based on so-called "objective" data, namely sound objects in the sense of [44], [45], articulated with evaluative variables issued from "kine-perceptual impressions" of the landscape experiment. Beyond Euclidean abstraction, those evaluative variables are constituted by anthropocentric data implementation. The audibility of this landscape structure through the set of descriptive and evaluative variables implies a construction of the sonoscenes thanks to a complex combination between the analogue elements of environment, constituting the "real" part of the soundscape, and the metaphorical ones, thus constituting the soundscape "imaginary" part in both mathematical and phenomenal acceptation. Imaginary part of the soundscape, within heterogeneous, anthropic-centered space, embedded by the subject, oriented by the gaze, the auditory attention, the direction of movement, its own lateralization, elevation, requires a particular attention for sound sources spatialisation within the built ideoscene, with using multichannel capture and reproduction techniques. Therefore, sound spatialization is processed through a 4–channels recording device, associated with a specialized 4-capsules microphone (Soundfield®). Called "B-format". This technique consists into acquiring the omnidirectional sound pressure signal associated with the three first-order pressure gradient components along the three Cartesian axes (x, y, z) of the surrounding space. Multichannel device is therefore able to reproduce the spatial components of the diffused sound signal.

Through sound spatialisation within the perception sphere, the corresponding evaluative variables implies a geotopic dimensioning of the ambiences sources, showing the position of surrounding objects (land- or soundscape sources), framing of the sensory medium (vision or hearing) and distance apprehension from the perceptual bubble(s). This articulation of the anthropocentric relation of objects with their analogical contents is likely to be apprehended as a psycho-geographical landscape construction: [46], then [6] have attempted to articulate these two Cartesian designs and anthropo-center of space, to find passage points, connections

between the descriptions of the behavior, actions, perceptions and representations. This articulation of the analog description with the metaphorical projection sign the Euclido-perceptive space fundamental heterogeneity of the perceived environment, the ambiantopes. In this sense, ambiantopes articulates the sensitive structure of the landscape representations to constitute the association of the environmental elements structuring the perceptive sphere of the user of space.

To resume, VR systems have to make emerge the identity functions of landscape experiences in the city, through soundscape complexity revealing in the two terms of the current, actual reality, and the imaginary, namely the metaphorical projection of the sound environment on the listener landscape experience, the two dimensions of which constituting his ambiantope.

5. Interactional Cognitive Structures of Sound Perception

5.1. The Landscape Metaphor

The notion of metaphorical projection action can be lightened by experiential cognition scientific literacy, which "theory of conceptual metaphors" [47] suggests that in order to understand the domains of experience on which we have no direct grasp (affects, abstract concepts,...), we call sets of "patterns" or structures directly emerged from well-known fields of experience [48], [49]. In this sense, the whole body of the VR explorer, in its relationship to the surrounding real or virtual spatial world, constitutes the place of mental anchoring of these patterns, themselves derived from the process of environmental impression of his corporeity. From all interactions with the environment emerges a regularity, making it possible to understand our direct experience with the environment. The emergence of these regularities, or patterns, help to understand experiences directly from a domain of our experience, structured by a set of "image-schemas" that have previously been built by the history of our interactions with the environment.

Borrowed from the concept of corporeal schema introduced by Gestalt theory ([50], [51]), the image-schema describes the image of the body that takes the place of the sensory complex originating from the kinesthetic sensation. By extension, the image-schema is an interaction pattern that provides a cognitive reference function, used in psychology for a very long time. "*This image gradually took the place of the sensory complex originating from the tactile and kinesthetic sensations*." ([52], p. 303). *"... the final result of the tests allowing the evaluation of the posture or the passive movement presents itself to the consciousness as a postural modification brought back to a standard. For this standard of integration, with which all subsequent modifications of posture are evaluated before entering consciousness, we propose the word schema.* "([53], p. 102). More specifically, a metaphorical projection is performing by substituting to an abstract object a part of the image-schematic structure of our perceptual experiences, which provides the interaction patterns a cognitive reference function: "*The metaphor is conceived here not as a figure of language, but as a fundamental cognitive tool, which allows us to understand a field of experience in the terms of another: it partially and systematically projects the structure of a target domain on a source domain, so that inferences and implications specific to the source domain are applicable to the target domain*" ([54], p. 4).

This form of mediation between the perceived environment and the perceiving subject constitute the background of the "impression" process, referring to the "imprint" mechanism. The latter relies on a perceptive regularity which makes possible environmental mediation through the understanding of our direct experience of the environment, without any precondition or analysis procedure, by allowing solidification of acquired knowledge elements. The emergence of these patterns provides a structure for understanding our recurring experiences and allows us to understand one area of our experience that has emerged directly from the history of our interactions. During the navigation process, the embodiment of the kine-perceptual experience in our sensory-motor referential then constitutes a sort of "*recurrent structure, charged with meaning, traducing our experiences, mainly at the level of the manipulation of objects and perceptual interactions*" ([54], p. 4).

As illustrated figure 1, these structures organize our mental representations, by shaping ambient scenes according to two modalities:

1. the Cartesian mode of analogical construction, which presupposes a direct transfer of the images-schemas in the act of consultation / documentary reconstruction ("Umwelt"),
2. the anthropocentric mode of metaphorical projection, where the images-schemas serve the teleological construction of the perceiving subject, by the idealized formalization of an imaginary situation ("Merkwelt").

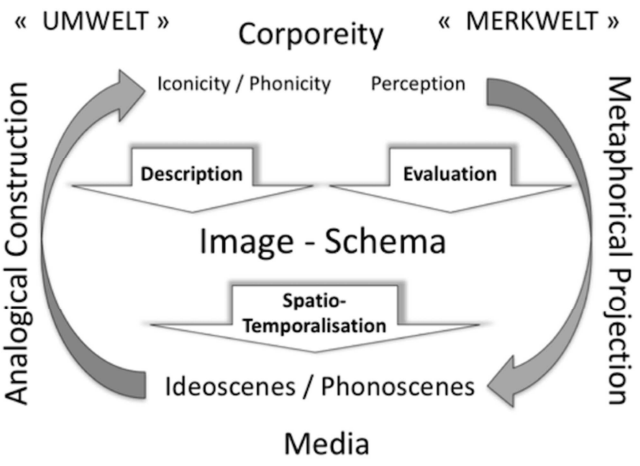


Figure 1. *Analogical-metaphorical system of soundscape recontextualisation [55].*

In German, the terms "Umwelt" refers to the analogical construction of the surrounding world, while "Merkwelt"

describes the teleological projection of the subject within his sensitive universe. These two notions constitute a good transcription of the articulated analogical description and metaphorical projection of the surrounding ambient objects, thus constituting the heterogeneous keystone of the inhabitants' environmental consciousness.

5.2. The Double Ontological Space of Sound: Ideoscenes

This double ontological apprehension of the sound space, on one side the descriptive variables of the environment in the Cartesian space, responding to the *analogue construction mode*, which organizes the physical environment and, in the other side, sensitive space attributes, anthropocentric, at the origin of the *metaphorical projection mode* within the "bubble" of the soundwalker, constitute the model of the transfer process from ambient sound phenomenon into a virtual immersive reproduction system.

As immersive systems solicit the dimension of immediate perception through direct transfer of image-schemas by analogical transcription of sources, teleological dimension of the sound environment mobilizes the images-schemas for the spatio-temporal hierarchizing of the sonoscene elements. Therefore, these analogical and metaphorical modalities imply a twin holistic and systemic codification of the remarkable sources of the soundscape for VR exploitation.

This codification is operated by images-schemas implementation within the spatial and temporal references of the displacement, in terms of four-dimensional Cartesian coordinates of the listener's worldline. At every moment, the soundwalker receives in its anthropocentric universe a flux of sensations, perceptions, information and messages that organize, memorize itself in "scenes" succeeding one another in its consciousness, passing from a continuous flow to structured discrete impressions, also called *ideoscenes*.

Introduced by [46] then taken up by [6], the notion of ideoscene correspond to the flux of sensations, perceptions, informations and messages organised in "scenes" succeeding in man's consciousness, thus generating structured discrete impressions. Moreover, ideoscenes describes the images-schemas production in the sense of the memo-kinesthetic inscription on a spatialized support. It is here represented by the corresponding worldline, in which ideoscenes describe the crystallizations-memories of the land- or soundwalker representations. During the soundwalk, ideoscenes, also called sonoscenes, are assembled, deformed and recombined to participate in the complex representation of ambiences.

6. Interaction Dynamics Time Modelling

6.1. A Complex Space for Ideoscene Representation

Within an immersive VR system, ideoscenes are rebuilt in the complex -real-imagined- space of perception, to be re-activated during a virtual exploration through the urban maze [56]. Ideoscene structures then constitute a sort of "cognitive map" of the felt atmosphere, to be implemented within the VR immersive device. Thus, through describing the system of apprehension-understanding of the environment by the operation of conceptual metaphorical projection [48], ideoscenes define the functional structure of cognitive systems allowing coding (re-production) and decoding (re-cognition) the heard soundscape within a virtual reality system.

In this theoretical framework, ambience acknowledgement is understood as a mechanism to formulate hypothesis, to be compared step by step with the close-order environment perception. This so- called "behavioral internalization" principle determines the interaction evolution by the permanent adaptation of the subject cognitive system to his actions during his navigation. Also used in artificial intelligence systems, these rules determine the evolution of the cognitive system of the VR explorer by the permanent adaptation of his cognitive skills to its sensory-motor system.

6.2. Time as an Interaction Behavioral Revealer

Principle of evolutionary systems inertia [32] considers time as a coding axis of the navigation process, and the time signature of this adaptation process is measured by its differential entropy value [57], understood as the amount of information grabbed at every moment of the navigation.

Through the process of abstraction, the resulting environmental mediation in the form of a metaphor organizes the coding and recognition of the states of the environment at a given moment. This coding operation is here used in sensory immersion systems within virtual or augmented reality devices and is called "vicariant correspondence" in viability theory [31], thus offering several possible paths between a given stimulus and response. It is therefore naturally multi-faceted, as opposed to the univocity of the classical stimulus-response processes defined by the behaviorist school. If the perception and action correspondences make the listener possible to internalize his environment, the vicariant correspondence internalizes his behaviors, *via* the transcription of the metaphorical projections, image-schemas, into ideoscenes. It is within the framework of the viability theory that the regulon, thus describing this regulation process, aims at preserving the viability of the whole system through signing all the regularities, temporal permanencies or state invariances, which evolve over time. This regulon constitutes, in a way, a tychastic signature of the emergent behaviors of the environmental interaction system. Its corresponding regulation process allows change of the cognitive skills during a modification of the perceived environment, or, more prosaically, a change in the process of perception by addition or withdrawal of a sensory modality, change of perceptual target or modification of the vicarial interaction itself.

By integrating step by step information from environmental feedback, gradual construction of landscape

knowledge by the subject wandering in a VR system feeds the interactive navigation as a dynamic process, which data loss or gain depends on its pre-requisites, its culture. These data treatments are mainly conditioned by a regulation mechanism governing the "fast evolution" moments of the interaction system, within "low evolution" periods, long-term states. Revealed by the "regulation signatures" of the navigation process, these "fast evolution" moments of the interaction situation are defined as "opportunity windows" in the paradigm of evolutionary complex systems, instants where the potentialities of the elements interaction chain of the perception system are maximal. These opportunity windows represent a sort of temporal marker integrating dated knowledge during the soundwalk, the more old and difficult to access, the more perennial. This constitutes the principle of "imprint inertia" [31]: at each stage of ambient acknowledgement during the exploration, environmental assessment is a representation of the vicariant sub-correspondence learned to date. Consequently, the hetero-chronical evolution of ambient acknowledgement using time as the coding axis of learning behaviors reflects the logic of constant solidification of the oldest strata of the "experienced" data. This notion of "successive and cumulative learning" can be found in many examples of human acknowledgement processes, where studies of learning acquisition shows that students skills perception follows a generic evolution pattern during their training cursus [58], or animal ethology, showing that animal migrations or, more generally, “untrained” social behaviors are a consequence of an intergenerational practice.

6.3. Cognition as an Adaptive Process

Thus, temporal assessment of the VR navigation dynamics allows to describe the adaptive function between the listener and the sound environment, which asymptote signs the environmental reification, and the end of the interaction process. This illustrates the process of sensory-motor abstraction, which allows the identification of the same object or situation by means of distinct sensory perceptions. Therefore, constituted regulated perception system prescribes a “regulation correspondence”, which models the “adaptive learning rule” by operating a symbolic construction from the built ideoscenes. This construction, also called “Informational impedance adaptation” by [6], acts though the apprenticeship process as an adaptive function which asymptote reveals perfect fitting between transmitter and receiver directories. This interaction links sensory-motor processes to environmental behaviors, while internalizing them in the cognitive sphere. This principle of “perception-action feedback” constitutes the basis of the informational acquisition process during a virtual soundwalk. As feedback loops of regulation processes are apprehended from a quantitative point of view not as a primitive, but rather as a derivative, that is, by recalculating the initial data at each step of the interaction evolution, knowledge acquisition during a VR soundwalk is relevant to dynamic systems “classically” formulated by differential equations. As a consequence, variables of the soundwalker’s perceived environment take source within the analogical/metaphorical complex space dimensioning as shown following figure 2:

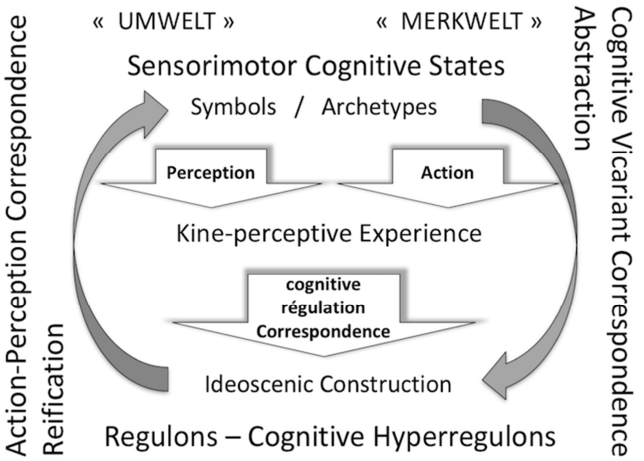


Figure 2. *Regulation correspondence, or adaptive learning rule: abstraction-reification circuits of the knowledge acquisition process.*

This procedure allows the exploration system to import the percepts in symbolic forms that have the capacity to transcribe the structural properties of the soundwalker’s perceived environment within the (actual/virtual) complex space.

7. Conclusion

In order to rebuild daily soundscapes, hypermedia VR modelling has made it possible to reveal the relations of interdependence between environmental elements -objects, ideas, feelings, emotions, phenomena- and their meaning -symbolical and teleological assumptions- by integrating multiple links of the corpus of complex sound atmospheres within a spatialized immersive system. Elementary units of the acoustic environment, the sound sources, associated to their time hierarchical distribution, constitutes the basis of the phenomenal apprehension of the soundscape. The multi-scale formalization levels that characterize the hypermedia structure of the soundscape reconstruction reflect the remarkable patterns of the perceived sound environment on a human scale. Sound atmospheres, and more generally ambiences, can then be reproduced according to sensitive and imaginary modalities of the subject’s perception, thus mobilizing analog and metaphorical cognitive skills.

By approaching a continuous time problem, the navigation worldline of the soundwalker, by data collected in discrete time, namely the environmental analysis of the soundscape sources, the time taken as coding benchmark for navigation behaviors makes it possible to formulate the interaction mode with the environment. Time-tabulation of the set of quantized states information within the complex space of interaction thus enables a twin holistic-systemic ambiantal codification.

Moreover, by integrating synchronous spatialisation between soundscape and visual landscape, virtual reality systems allow to solve the difficult question of participatory investigations by finding new ways to integrate sonic notions

or concepts by the reconstruction of soundscapes.

With proposing this form of ambience restitution procedure, HAUP system thus makes it possible to share sensitive dimensions of the landscape, by replacing classical analysis using verbal survey with sound manipulations in hypermedia navigation mode.

Aimed to constitute instrumental bases for in-lab observatories of the lived environments, virtual reproduction techniques offer a way to develop shared analytical skills between users and territorial decision-makers, in order to establish a dialogue between actors and users of the urban space, for a better mediation of landscape information.

Acknowledgements

HAUP project has been initiated by a collaboration between ESO laboratory UMR 6590 and AAU laboratory UMR 1563 (Bruno Suner), with the support of Rennes 2 University, CNRS and MSH Network.

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