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Acoustic Shadows

an auditory exploration of the sense of space

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Abstract

This paper examines the question of auditory detection of the movements of silent objects in noisy environments. The approach to studying and exploring this phenomenon is primarily based on the framework of the ecology of perception defined by James Gibson (Gibson, 1979) in the sense that it focuses on the direct auditory perception of events, or "structured energy that specifies properties of the environment" (Michaels & Carello, 1981, p. 157). The goal of this study is triple:

– Theoretical: for various reasons, this kind of acoustic situation has not been extensively studied by traditional acoustics and psychoacoustics, therefore, this project demonstrates and supports the pertinence of the ecology of perception for the description and explanation of such complex phenomena.

– Practical: like echolocation, perception of acoustic shadows can be improved by practice; this project intends to contribute to the acknowledgement of this way of listening and to help individuals placed in noisy environments without the support of vision acquiring a detailed detection of the movements occurring in these environments.

– Artistic: this project explores a new artistic expression based on the creation and exploration of complex multisensory environments. 'Acoustic Shadows', a multimedia interactive composition is being developed on the premises of the ecological approach to perception.

The last dimension of this project is meant to be a contribution to the sonic representation of space in films and in computer-generated virtual environments by producing simulations of acoustic shadows.

Prelude

Last summer, while flying back from France, sitting in the airplane and daydreaming, eyes closed, I realised that I could clearly detect the movements of other travellers up and down the aisle. I did not actually hear the sounds generated by their movements, masked as they were by the loud, constant and diffused background noise of the aircraft, but I could feel them, and without any mistake, I was able to perceive and understand all the displacements of the passengers. I spent most of the 9 hours of the flight, testing the accuracy of this perception, and wondering to what sense it related: was it touch and did I feel the movements of air displaced by the passengers or the changes in the air temperature? Was it smell? Or sight?

Landing in DFW, I had acquired the certitude that this perception was indeed related to the sense of hearing and I already had a name for the perceived phenomenon: Acoustic Shadows.

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The fundamental characteristic of AS is that they are best perceived in relatively loud sonic environment, almost drowned in a diffused broadband noise. The clarity of the perception is intimately related to the diffuseness of the background noise and to the presence of high frequencies in its spectrum.

The environment is crucial to the occurrence of Acoustic Shadows that can be described as the perception of the variations of some of the auditory qualities, mainly spectral composition, phase and intensity of the sonic environment.

Listening to these tenuous variations is motivated by an intention that does not aim to the actual sounds caused by the movements of beings and objects, these sounds being masked by the environmental background noise, but to the background noise itself.

This radical shift in the act of listening appears at first to be counter-intuitive or in total contradiction with the usual practice in which the background noise, analysed as invariant and meaningless, is cancelled out to better track sound signals created by moving objects. I must say that it is my practice of contemplative and analytical listening to the sound environment that led me to identifying Acoustic Shadows. It is possible to identify the perception of Acoustic Shadows as some sort of 'specialised' listening, developed with the scope of compensating for the lack or the difficulty to acquire direct sound cues from the objects themselves or for the lack of visual cues.

Acoustic Shadows, acoustics, psychoacoustics and audiology

The goal of this section is to clearly define the phenomenon of Acoustic Shadows to identify relevant existing studies in the fields of acoustics, psychoacoustics and audiology, and to further explain why the ecological approach to perception is perfectly suited to its analysis.

The term Acoustic Shadows (AS) implies a strict analogy to the visual phenomenon of shadows and designates the perceivable transformations that bodies cast on the flow of energy in which they are placed. This analogy in itself points to the first and most important characteristic of AS, that is the presence, in the environment, of a flow of acoustic energy, independent of the body. Like their visual equivalents necessitating light, AS require some sort of sound or ambient noise to be perceived. This fundamental dependence on an acoustic energy that is not actually produced by the object itself as well as the triangular interactions between the body, the listener and the environmental sound, can be seen as part of the explanation for the limited scientific effort dedicated to this phenomenon.

Acoustics, traditionally focusing on the study of production, propagation and perception of sound, tends to ground these three domains on what seems to be a natural linkage between an object and the sound it produces. Any acoustic phenomenon is thus scientifically represented or modelled by a significant and manageable pair of components, each pair being characteristic of each domain: production of sound will focus on the object producing the sound and the produced signal; propagation of sound will focus on the sound waves and surfaces; and perception of sound, on the sound source and the listener. Very rarely would a third component be introduced in these dual models.

The study of the perception of obstacles by blind people clearly reveals the limits imposed on acoustic research by these two-dimensional models for the simple reason that, most of the times, the obstacles are silent.

The awareness of the presence and location of silent objects was a well-known phenomenon commonly described as 'facial vision' and presented as a mysteriously accurate tactile capacity gifted to some rare individuals. The French philosopher, Denis Diderot, in 'The Letter on the Blinds' (Diderot, 1749) explains extensively how his fictional blind character had trained his other senses to acquire detailed information on the world around him. "The blind man from Puiseaux evaluates the proximity of a fire by the variations of its heat; the fullness of cups by the sounds of the fluids he pours in, and the presence of bodies by the action of air on his face" (Diderot, 1749, p. 20; my translation).

According to the two-dimensional model of the scientific study of auditory perception based on the sound source and the listener, the role of sound in the cognitive exploration of the world by blinds was strictly limited to the acquisition of information directly connected to the sound source and to its relationship to the listener. Distance to the listener, size and other auditory qualities of the source such as pitch and timbre formed the scientific set of information made acoustically available to the blind. The awareness of other qualities of silent objects was assigned to the sense of touch in the same dualist manner: shape, texture, weight, thickness, and even presence formed another set of information, distinct from the previous one and made available to the blind through subtle tactile interactions with objects.

It is not until the work of Cotzin, Dallenbach and Supa (Cotzin, Dallenbach, & Supa, 1944) in the 40s that the mystery of 'facial vision' was redefined as an auditory perception. The conclusions drawn from their experiments clearly state that "aural stimulation is both a *necessary* and *sufficient* condition for the detection of obstacles" (Cotzin, Dallenbach, & Supa, 1944, p. 182).

This important discovery made by a team of psychologists at Cornell University was contemporaneous of the work of Donald Griffin, a zoologist, who identified 'echolocation' as being what was previously named the 'sixth sense' of bats (Griffin, 1959).

In both cases, it had been proven that detection of obstacles was performed by analysing the reflexions of sounds on the obstacles. On the basis of this new model, implying a listener, a reflecting object and a signal, a lot of further experiments have been conducted, most of them very beneficial to blind and visually impaired people.[1]

Amongst these experiments and of a great interest to our study is the work of Daniel Ashmead and Robert Wall (Ashmead & Wall, 1999) that shows that perception of spectral transformations of a background noise caused by reflections on large obstacles are meaningful and useful in orientation and mobility tasks. "Perceiving the presence of a nearby wall is based on a spectral shift toward the low frequency region, and not necessarily on an overall increase in sound level" (Ashmead & Wall, 1999, p. 320).

Other important points revealed by this study are the differences between this perception of silent obstacles and echolocation on one hand and detection of 'sound shadows' or 'sound holes' on the other hand.

Echolocation deals primarily with the reflection of high-pitched sounds generated by the perceiver on obstacles. In this process, the perceiver controls the signal and particularly its pitch, onset and intensity, all parameters necessary for comparison to the reflected signal by which echolocation can be performed.

'Sound holes' or 'sound shadows' are caused by obstacles placed between the listener and the sound source that absorb or reflect part of the sound wave, "if there is traffic noise coming from the far side of the object, then there is a sound shadow or hole in the ambient noise. [...] In these situations the acoustic information consists of rather strong variations in the amplitude and frequency of sound coming from a certain direction" (ibid.).

This general phenomenon of sound occlusion is described by James Gibson and also termed as "sound shadows" (Gibson, 1966, p. 81) and encompasses the transformations applied to an incoming sound by the head of the listener. Particular attention has been given to this aspect of 'sound shadow', sometimes also named 'head shadow', as it is in part responsible for the localisation of sound sources by analysis of the diffraction of the lower part of the spectrum around the head as well and the absorption of the higher part of the spectrum.

Finally, this study points to the necessity to adopt a consistent terminology to describe auditory phenomena in order to avoid misleading assimilations and aggregation. Our use of the term Acoustic Shadows is strictly consistent with the existing literature and represents an exact illustration of a particular instance of the broader phenomenon of Acoustic Shadows described by Michael Gordon and Lawrence Rosenblum: "A surface obstructing a sound source may mediate, reflect, refract, and absorb the acoustic signal. The resultant structure originating from the source sound may be better conceptualized as an *acoustic shadow* than as an occluded sound per se" (Gordon & Rosenblum, 2004, p. 88).

The second reason calling for a different approach is that AS are much more accurately perceived when the listener or the object is moving, unlike echoloca-

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tion that is mainly oriented towards the detection of fixed obstacles. If echolocation deals with the detection of the position of objects, Acoustic Shadows deal with the detection of moving bodies based on the perception of changes in the auditory environment. Acoustic Shadows inform on events in our surroundings and not on fixed properties of objects or geometrically modelled space. The changing relationships between the environment, the flow of acoustic energy displayed in this environment, objects or bodies placed and moving in the environment and a listener form the ecological dimension of the perception of Acoustic Shadows. This implies that, in our study, we are looking for dynamic spatio-temporal properties, continuously and constantly modulated by the movements in space of objects and observed from the position of a mobile perceiver. In this sense, a theoretical framework based on the linkage of perception and action, similar to that of active perception developed by Alva Noë, is more apt to support our investigations, in which we are primarily focusing on the temporal dimension of the perceptual phenomenon that we will then connect to its acoustic realisations.

> It is because mobile perceivers gain access to variation in perspectival properties as they move about that the actual spatial properties of objects are made available to the subject for experience. The world is made available to us in a way that is determined by the fact that we occupy a tentative and shifting place within the world. All perception is perspectival in this way. (Noë, 2006, p. 88)

Finally, we assume, in complete accordance with James Gibson, that the input for perception is not constituted by raw data requiring signal processing from the brain to deliver valuable information. "The perceptual systems, including the nerve centers at various levels up to the brain, are ways of seeking and extracting information about the environment from the flowing array of ambient energy" (Gibson, 1966, p. 5).

Traditional acoustics and its developments in psychoacoustics and audiology are mainly framed by the approach called indirect perception in which it is assumed that "the senses are provided with an impoverished description of the world" (Michaels & Carello, 1981, p. 2) that requires further information processing in order to form a realistic image of the world. Another assumption attached to this approach is that the stimuli are discrete "time slices" each of them "meaningless until related to other moments already identified and held in memory [...] and described in terms of very low-level physical variables" (ibid., p. 9).

When analysed from this perspective, Acoustic Shadows appear as a very complex set of interactions between a listener, an object and environmental sounds and relying on the processing of extremely thin auditory stimuli, almost at the threshold of normal perception. Thus, the study of AS within this sole framework would imply the analysis of the phenomenon as a temporal series of pairs of discrete stimuli and

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responses related to two-way interactions between the three components of the phenomenon, the listener, the object and the environmental sound. Even though we acknowledge the necessity to produce this series of measures for further synthesis of AS, we argue that a hollistic study that primarily focuses on the perception of a significant change in the structure of the acoustic energy in the environment, instantly informing the listener with the behaviours and qualities of moving bodies in his surroundings, will allow us to gain a better understanding of the interactions contributing to this perception and to better design the two-dimensional models necessary for the analysis of AS.

The ecological approach to Acoustic Shadows

This section examines the reality of Acoustic Shadows and their formulation in terms of an ecological approach to auditory perception and then proposes methods to experimentally study and simulate them.

The first question, 'Do Acoustic Shadows exist and are they really perceived?', has been examined in two ways.

The first one consisted of a questionnaire (see Appendix) given to a group of 18 students, asking them if they had experienced such a sensation as being aware of the presence or movement of a body, human or animal, without having actually sensed its presence by direct visual or auditory cues. All the students declared to have experienced such a situation and most (10 out of 18) of the descriptions of this experience implied the perception of changes in the background sound environment. Other descriptions referred to a change in 'pressure', 'electricity', 'tension' or 'heat of the air'.[2]

The second way, by which we addressed the question of the actual existence of the phenomenon, consisted in placing subjects[3] in the centre of the diffuse sound field of a noisy environment consisting of the sound laboratory in which white noise was diffused by a 5.1 sound system. The intensity of the noise was set to approximately match the sound level of the ambient sound present in my earlier experiences. Subjects were blindfolded and, in a first experiment, I silently walked laterally in front and behind them at various distances ranging from a half metre to two metres. All subjects declared to equally 'sense' my movement in front and behind and all of them could identify the direction and speed of my movement.

Other experiments in the same setting were conducted in which pieces of acoustic foam of various shapes and volumes, attached to strings and thin poles, were silently displaced at different speeds and in different directions in front and behind the subjects. In most cases, the movements were clearly perceived with results depending on the intensity of the noise, the size of the piece of foam and the distance to the subject. In the most favourable cases, some subjects were able

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to indicate together with the distance, direction and speed of the movement, the approximate size of the piece of foam. This experiment showed that movements of the smallest objects were best perceived with the objects placed behind the subjects and moving faster.[4] It is interesting to notice that for small objects, fast (a second or less than a second per cycle) periodic movements of small amplitude (below a half metre) were better detected.

The results of these basic experiments give us enough evidence of the perception of movements of silent absorptive bodies in a noisy environment.

We realise that all of these findings will need further investigation and the design of more selective experimental methods.

'Why do we hear Acoustic Shadows?' is the fundamental question inspired by an ecological approach.

It is helpful, in the attempt to answer this question, to try to imagine ourselves living in the natural habitat of our very distant ancestors: the deep forests or the marshes where vegetation and prey were plenty. This dense, complex and continuously changing environment requires for basic survival purposes a constant attention to a very broad range of events regardless of their physical manifestations or realisations i.e. visual, acoustic, olfactive, tactile or even gustative. When considered from the sole auditory standpoint, this environment is characterised by the predominant presence of a scattered noise field, resulting from the combination of broadband noises of the nearby streams of water and from the wind passing through branches with multiple sound signals (insects, birds) reverberated on hard surfaces such as rocks and trees: all of this creating a very unfavourable context for a gathering of information on the surroundings solely based on cues acquired by the detection of the sounds directly produced by animals. The situation is similar for the other senses identically overwhelmed and obstructed by numerous signals and cues. In such a situation, it is more than probable that a successful strategy for recovering meaningful events such as the approaching of an animal, occurring in the surroundings, should be based on the observation of longer-term time varying properties, rather than instant properties or short signals. Especially when the approaching animal, should it be prey or predator, knows how to move without making any noise, has a relatively acoustic-absorptive body (furry), and has developed an efficient strategy of visual and acoustic camouflage. However, in most cases, the event of the approaching animal has been sensed and we propose that it was sensed by Acoustic Shadows: the direct acquisition of information on the movements of bodies in the surroundings by means of perception of variations of acoustic properties of the background noise, very similar to the variations of visual properties of the overall optical flow generated by various surfaces (Gibson, 1979).

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'How do we hear Acoustic Shadows?' 'And what are the different strategies implied in the perception of Acoustic Shadows?' With the answer to these questions, we will try to identify the various parameters responsible for this perception and their correlations.

Characteristics of the object and their impact on the environmental noise:
Because of the acoustic quality (i.e. mainly absorptive) of the bodies generating Acoustic Shadows in real world experiments, we have used for our experiments cubes of acoustic foam with sides ranging from 25 centimetres to one metre.

We assume that, in most cases, the high part of the frequency spectrum of the ambient sound is progressively blocked by the approaching object, while the low part of the spectrum is diffracted. This results in five types of changes of acoustic properties perceivable in the background noise:

Timbre or colour of the noise as a result of the alteration of the spectrum due to the absorption of treble frequencies.

Overall intensity of the noise, changing as a direct factor of the size and distance of the object.

Variations of phase of the diffracted bass frequencies manifested by interference patterns for these frequencies.

Interaural spectrum differences.

Interaural time differences.

Characteristics of the background noise:
The most favourable layout for the perception of AS are: Outdoors with traffic or typical urban noises such as air conditioning units, electric transformers and multiple random discrete noises such as footsteps; outdoors with natural broadband noises produced by waterfalls, distant ocean, wind in trees and high density layers of discrete treble sounds such as bird song or insects noises; or indoors with diffused noises such as hums and low-pitched sounds of electrical devices such as transformers and various types of ventilation.

Characteristics of the motion:
We have conducted our experiments with only movements on straight lines parallel or perpendicular to the ears axis. It has been noticed in most cases that lateral movements (objects moving on parallel lines, from one side to another side of the listener) were more clearly identified than the transversal ones (objects moving on perpendicular lines, away or closer to the listener).

We have not explored the perception of vertical movements.

Faster movements (roughly three metres per second) have in all cases been best perceived than the slower ones (one metre per second).

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Relative position of the object:
In all our experiments objects have been located on a horizontal plane at the azimuth of the listener's ears with medium distance ranging from a half metre to three and a half metres.

Several sets of data consisting in the audio recordings of silently moving objects in a diffused sound field have been produced using two types of combinations of microphones: one single omnidirectional microphone, and an ORTF set of directional microphones. These recordings have been played over the same sound system used to generate the diffused sound field for the recordings to ten trained listeners. For the stereophonic recordings, most of them (eight) were able to detect the lateral movements of the object, and five of them were able to perceive the transversal ones. For the monophonic recordings, only two listeners were able to identify the transversal movement and none of them was able to perceive the lateral movement.

These recordings have been used to measure the ranges of variations of the identified acoustic properties and to provide data for further attempts to synthesise the phenomenon of Acoustic Shadows.

In a preliminary set of attempts to synthesise AS, discrete and continuous changes (within the measured ranges of recording of experiments) have been applied to one only of these acoustic properties (spectrum, intensity and phase) of the background noise: none of these individual changes was sufficient to simulate for a listener the movement of an object. Furthermore, the sole change of intensity, if associated to a movement, was always associated to a movement of the sound source itself ("The noise is coming closer" or "The noise is moving away") in the opposite direction of that of a supposed occluding object.

The design of a model for the dynamic intermodulation of the three qualities of the background noise is still in progress and will constitute one of the next phases of this project.

We believe and have given evidence that the acoustic information formed by the movements of silent moving objects on the diffuse field of acoustic energy of an environment is clearly perceivable. Based on our study of examples of this perception and of previous studies, we can infer that this perception relies mainly on spectral changes in the bass region of the spectrum and changes in phase as well as changes in intensity. We propose that Acoustic Shadows, defined as the set of transformations imposed on a train of acoustic waves by a mobile or fixed object, convey rich information on this object and its movement and imply a complex shifting pick-up of various patterns of variations.

This is where our systematic investigation of Acoustic Shadows stops. We are aware that these experiments do not form a scientific body of data from which one could bring definite conclusions on the phenomenon of Acoustic Shadows, we are publishing them as they are, with the hope that researchers in psychoacoustics and

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acoustics would pursue the exploration of this phenomenon, using the scientific method relevant to their field.

Our goal was to attract attention on this dimension of auditory perception and especially in its relationship with what could be defined as the sense of movement. This is this sense that our artistic experimentation will be exploring further.

The artistic experimentation inspired by Acoustic Shadows

My musical practice is directly inspired by Schaeffer's 'Musique Concrète' (Schaeffer, 1966), and particularly by its phenomenological approach in which time is not thought of as an abstract, objective and linear dimension on which musical objects, i.e. the notes, are displayed. Time, in this framework, does not refer only to the length of intervals between two notes, but to the inner temporal quality of the sound objects: their duration.

In accordance with Schaeffer's description of abstract music, it can be said that the notes, i.e. the primary material of this expression, are conceived as objects of indirect perception, which means that the information attached to them is limited to their instant and discrete values. Their meaning depends upon an interpretation performed by the listener, in accordance to a system previously acquired and in a temporal dimension different from that of the perception of the sonic events themselves. In this context, a musical note does not make sense by itself and does not contain any meaning in itself; it is only at a 'higher' level, a level of memorisation and conceptualisation, that the note acquires a meaning. Traditional Western music, in this sense, is strongly related to theories of indirect perception that "consider the stimulus to be a discrete time-slice. Naturally, such a moment is thought to be meaningless until it can be related to other moments already indentified and held in memory" (Michaels & Carello, 1981, p. 9).

In contrast, in the 'Musique Concrète' approach, sound objects are thought of as objects of direct perception; they deliver information along with their perception, they make sense, in a direct manner, through the display of their acoustic invariants, of the frequency spectrum and the transients of the wave train that specify the event (Gibson, 1966, p. 81).

The sound objects of 'Musique Concrète' are ecological auditory events, or selected for their capacity to deliver direct information on a real or imaginary energetic event. Through the evolution of their acoustic invariants, they continuously inform the listener of the unfolding of these events.

> While listening to the sound object provided by a creaking door, we could disregard the door to focus on the creaking. But the history of the door and that of the creaking exactly coincide over time: the consistency of the sound object is that of the energetic event. (Schaeffer, 1966, p. 271; my translation.)

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Sound objects point to the dimension of time constituted by duration, or by the preservation of an identity throughout changes over time. "If instead of using objects essentially conceived to mark temporal locations, we use objects containing temporal information, the arithmetic time disappears to reveal the perception of durations in obvious relationship with the content of these objects" (ibid., p. 246; my translation).

The dimension of time revealed by this type of music strongly resonates within Gibson's description of the flow of ecological events. Time and space appear as the ghosts, the underlying entities of movements, events and sounds (Gibson, 1979, p. 101).

The audiovisual works related to Acoustic Shadows,[5] primarily designed as flows of audiovisual events fostering the emergence of a spatio-temporal continuum, were all intended to bring this dimension of time and space to the awareness of spectators while exemplifying the experience of the perception of AS. The visual and auditory components of these works consisted in the presentation of movements exploring variations of speed, distance, direction and acceleration. The first work, 'Soft Thresholds', used a 3D auditory space to present the audience with simulated Acoustic Shadows, accompanied by a visual representation of the simulated movements. This first work was used to test the assumptions previously made on the acoustic parameters responsible for the perception of AS. One layer of the musical part consisted in a very dense broadband sound, modulated in intensity by a slow pulse and diffused equally on the six speakers of the surround system. Variations of phase and spectrum were applied to the output channels individually in order to simulate AS. The second sonic layer consisted of sound objects whose trajectories were driven by 3D panoramic effects and the use of filtering processes derived from Head Related Transfer Function. The visual component, projected on a large screen on stage, was designed as the representation of the movements suggested by the sound environment.

'Acoustic Shadows', was an interactive audiovisual installation using identical sonic and visual components, displayed in a relatively small room (450 m^3) in which a stereophonic microphone was 'listening' to the AS generated by the movements of the audience in the surround sound space. The incoming modulation was analysed in terms of phase, spectrum and intensity differences between the left and right input. This analysis informed a programme on the type of visual representations to display.

In both situations, the primary intention was to synthesise the articulations of the acoustic properties that had been analysed as constituting the perceptual invariants of AS. Composing in this framework was at first a matter of creating a plastic and fluid sonic material that could then by manipulated and sculpted according to the findings and intuitions derived from the psychoacoustic study of AS to allow

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the perception of invisible movements. The flow of these events, their sequential and adjacent orders were organised according to two dialectical principles: a plastic one, based on the inner qualities of the events themselves, and a tectonic one, based on a narrative sequencing inspired by the myth of Orpheus. The tension between these two principles found in this myth a meaningful resonance in the confrontation of the two dimensions of time to which Orpheus is exposed: the everlasting present of the Underworld, in which shadows move around, and the fugacious present of the human condition.

The second intention of these experiments was to evaluate the musical and narrative usability of Acoustic Shadows as well as their specific contribution to a musical and audiovisual experience.

The intimate connection of Acoustic Shadows to movements has proven to be very pertinent to explore the spatial dimension of music especially from the listener's perspective. Acoustic Shadows are not strictly similar to sonic movements, created by panoramic effects simulating the displacement of a sound source from one loudspeaker to another by a gradual change of intensity. Acoustic Shadows simulate the movement and presence of an object or body *in* the space and not *over* the space, and it is from this perception of a body or object in space that space is revealed, not as an image but as an experience: very similar in its manifestations to the experiences designed by composer Maryanne Amacher:

> Thresholds. Physiological resonances. Acoustic spaces of felt sound phenomena, experienced either subliminally, or making recognizably direct physical resonances to the body. Composite mental images of immersion in space, as in stereo vision; direct physiological experience of an acoustic space, as distinguished from the perception of an acoustic space, aurally, as 'image'. (Amacher, 2009)

Further research and conclusions

Besides artistic experiments, the sensory awareness of space supported by Acoustic Shadows can lead to fruitful applications in various contexts. The main one is that of observers placed in noisy environments and with limited or no recourse at all from visual input. This is the case of blind people in everyday life, as well as of various types of workers operating in environments where visual information is masked or in environments saturated with visual information. Training strategies can be developed, encouraging the observers to listen to a specific type of variations of the background noises. Preventive strategies could also be imagined that would consist in creating special locations where Acoustic Shadows could be formed by generating background noise or implementing special architectural layouts.

The other context is that of the audiovisual industry of entertainment, including film and video games.

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The generalised use of 3D images in film and in video games has contributed to placing a strong emphasis on the representation of space and on the realism of this representation. Sophisticated visual effects benefitting from innovative technologies in digital imaging populate these imaginary spaces with objects and bodies animated with complex and fluid movements. Lights, shadows, textures, particles, applied with highly controlled fidelity, finalise and perfect these new illusions that actively challenge the sonic representation to the extent where the use of surround sound techniques does not seem sufficient to provide the expected counterpoint.

In film, sound effects, conceived as mobile sound sources attached to objects, allow the spectators to roughly track these objects in the space contained between the spectator and the surface screen. These effects fail to convey a full experience of space derived from the perception of positions and displacements of objects and mirroring the space suggested by the images. One of the reasons for this incapacity relies in the difference in nature between the two spaces involved: the purely imaginary space of the images and the realistic space supported by the surround sound system. The off-screen space, the main component of the imaginary space, is never perceived as the actual space surrounding the screen in the theatre, and the movements in and out of the scene presented on the screen are never perceived as movements in the theatre around the screen. This conflicting relationship between the visual and the auditory spaces has been carefully analysed by Claude Bailbé in terms of consistency between 'visual perspective' and 'auditory field' (Bailbé, 1998). The auditory field is always a space perceived *inside* the theatre where the visual perspective is the opening of a space beyond the screen. Bailbé mentions that in rare occasions, when the soundtrack of a film is obtained from phase stereophonic recordings, "an aesthetic component emerges, that of the felt space. Unlike directional effects (ping-pong), the spatial component enriches the visual perspective with a fascinating depth" (ibid., p. 236).

Because Acoustic Shadows are very similar to phase stereophony in the sense that they refer to an auditory field centred on the listener, and because they result from a complex interaction between a sound environment, an object moving in this environment and a listener, they always initiate and support a direct involvement of the listener in the presented scene. A natural and intimate space instantly emerges from Acoustic Shadows, because this perception is primarily the perception of relationships between these components. The strong sense of realism conveyed by AS is established by the sensation of oneself being present in the environment as a listener. With the implementation of Acoustic Shadows, the auditory space, felt as a subjective experience, is much more suited to engage in creative interactions with the imaginary space of the images.

In video games and virtual reality displays, where the point of view is usually assigned to a fixed entity, i.e. the player as a character or the player as an observer, immersed in an environment, the relevance of Acoustic Shadows to the elaboration of realistic auditory scenes is equally obvious.

The main problem consists here in the ability to synthesise in real-time the transformations of background sounds allowing for the perception of Acoustic Shadows.

Appendix 1

1: Have you experienced the fact of sensing the presence of someone standing or moving behind or around you even before hearing or noticing this presence?

If yes, please describe this sensation.

2: Have you experienced the fact of sensing the movements of an animal before seeing or actually hearing the effects of these movements?

If yes, please describe this sensation.

3: Have you noticed situations where someone has *guessed* your presence without seeing or hearing you?

If yes, please describe this situation.

If possible, include in your descriptions: the ambient noise present at this moment, the place in which this happened and the locations of the person or animal and of yourself in this location.

Appendix 2

Examples of answers to question 1:
"It feels like something is missing, like a hole in the ambient noise."

"I feel someone's presence because of a silent disturbance in the soundscape around me."

"I felt like a slight increase in tension in my chest."

Answers to question 2:
"This reminds me of a time in a butterfly garden where there was a small waterfall, I was able to feel a butterfly's presence both behind myself and my dad?"

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"I was in my bedroom where the most prominent noise was my computer and music at low volume. I was sitting on my bed, my back to the door, and my cat entered the room. I heard it."

Notes

1. For example, the system developed by Seki & Ito to simulate the presence of silent obstacles in diffused sound fields and to further train blind people to more accurately detect such obstacles (Seki & Ito, 2003).
2. See Appendix 2 for transcriptions of selected answers.
3. The subjects in all our experiments were undergraduate and graduate students in the Arts and Technology Program at the University of Texas at Dallas and enrolled in one of my sound design classes.
4. It is more than probable that Acoustic Shadows result of an evolutionary process by which the auditory system compensates for the spatial limits of sight. The capacity to sense bodies moving behind is certainly a vital need and this could very well explain why Acoustic Shadows are best perceived when coming from this direction.
5. 'Soft Thresholds' and 'Acoustic Shadows' have been designed and produced by Kristin Lee and Frank Dufour. 'Soft Thresholds', an audiovisual linear composition, was presented at the Cité de la Musique, Marseille, France, February 2011. 'Acoustic Shadows', an interactive Installation, was presented at the Vasarely Foundation, Aix en Provence, France, April-May 2011.

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