An Investigation Into Compositional Techniques Utilized For The Three-Dimensional Spatialization Of Electroacoustic Music

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Abstract

Presenting musical composition on a multi-channel loudspeaker configuration has now been practiced for over 60 years. Pierre Schaeffer in partnership with Pierre Henry composed a number of works, one of the works was *Symphonie pour un Homme Seul* (1950). The composition was presented on a tetrahedral configuration, which consisted of a frontal pair, a single rear and one elevated loudspeaker (Zvonar, 2004). This is an example of one of the first presentation of a music composition on a 3D multi-channel loudspeaker configuration. From that point onwards, many composer began to present their works on multi-channel loudspeaker configurations. One such composer, Karlheinz Stockhausen composed a number of works, which were presented on 3D speaker configurations. At the 1970 World Expo in Japan, Stockhausen helped design a spherical concert hall, which included 50 groups of loudspeakers set up in 3D (Cott, 1973). At this event a number of commissioned electroacoustic compositions were presented through the 3D setup. From the mid- 1970s onwards, the establishment of a number of 3D multi-channel loudspeaker diffusion systems began to emerge. An example of one such diffusion system is Birmingham ElectroAcoustic Sound Theatre (BEAST) founded in 1982 (Harrison, 1998). This system has the capability to mount up to 100 loudspeakers within one single configuration, including the possibility of placing speakers at an elevated position (Harrison and Wilson, 2010). Sonic Arts Research Centre (SARC) is another such diffusion system, which has loudspeakers located above as well as below the listening position. Please include the abstract sent to EMS.

Even thought humans perceive sound in 3D, the majority of electroacoustic works are still presented on two-dimensional (2D) loudspeaker configurations (Sazdov *et al.*, 2007). According to some, the creative possibilities of presenting electroacoustic music in three dimensions have not been adequately investigated (Sazdov *et al.*, 2007; Normandeau, 2009). The need to investigate how sound moves and how music is perceived in an immersive environment is required in order to fully realize the creative compositional possibilities of 3D loudspeaker configurations (Sazdov *et al.*, 2007; Normandeau, 2009). Considering that composers have engaged in loudspeaker distributed spatial music for decades, are there established practices used within multi-channel configurations? What can be learned from the stated opinions of electroacoustic music composers when engaging in 2D and 3D space?

This paper will argue that ecologically valid perceptual experiments are required in order to explore the creative compositional possibilities of 3D space. The argument is based on a

review of perceptual research in electroacoustic music, as well as a summary of spatial approaches and observations made by electroacoustic music composers.

Introduction

It is suggested that little is known about how space is perceived in a musical context or how musical gestures are perceived in space (Normandeau, 2009). According to some, the compositional possibilities of three-dimensional (3D) presentation of electroacoustic works have not been adequately explored (Sazdov *et al.*, 2007). It has also argued that research is needed to determine how space is perceived in a 3D environment in order to construct compositional techniques for electroacoustic music (Normandeau, 2009). To effectively identify how 3D musical space is perceived and how spatial compositional techniques can be formulated, it is first necessary to identify what attributes of multi-channel space are most commonly perceived by listeners. This is achieved by reviewing perceptual research in electroacoustic music involving listener participants and documenting perceptual observations made by electroacoustic composers when listening to multi-channel electroacoustic music.

A review of perceptual research undertaken of electroacoustic music is discussed which conclusions that there is little that directly addresses the spatial aspect of composition. A review of perceptual observations made by composers and survey-based research relating to multi-channel space reveals that a sense of "immersiveness" and "surroundness" are the attributes most commonly perceived. It will be argued that perceptual experiments within an ecologically valid environment can be designed to evaluation 3D multi-channel space for the purpose of creating compositional techniques for electroacoustic music.

Perceptual research in electroacoustic music

This section contains a review and analysis of perceptual research undertaken of electroacoustic music for the purpose of identifying what aspects of space listeners perceive. By reviewing research studies it is hoped that an appropriate methodological approach can be identified that specifically deals with how listeners perceive spatial aspects of electroacoustic music and how compositional techniques can be formulated from the analysis of listeners observations.

While investigating the various research studies, it emerged that researchers utilized three different methodological approaches. These are listener response studies (Delalande, 1998; Deliège, 1998; Bridger, 1989), Intention/reception (I/R) studies (Weale, 2005) and ecologically valid experimental design studies (Sazdov *et al.*, 2007; Adaire *et al.*, 2008). Listener response studies are empirical studies that classify listening behavior and listening strategies from the analysis of listener's response to presented works. This type of approach focuses on either defining typologies of listening behaviors or identifying pertinent sounding characteristics in presented electroacoustic works (Weale, 2005).

Deliège's (1989) perceptual research is concerned with the process of auditory grouping, where by the auditory system compiles different groups of elements of a song into different categories (i.e. rhythmic groups) creating a grouping schema in relation to the overall structural relevance of the song. Deliège perceptual experiments investigate how listeners formulate grouping of groups in relation to their perceived overall structural relevance, how listeners forms links between structures in a work and how structures are placed within the schema of the grouping of groups (Deliège, 1989).

This approach to auditory grouping involves undertaking a series of listening test during which listeners participants are asked to perform tasks.

One such task was designed to measure the degree of stability in segmentation judgment in which listener responses were recorded by pressing specific keys on a computer keyboards. Different keys signified a boundary start or ending of a subjectively perceived grouping or segment within a presented work. The responses from the participant were cross-referenced to identify correlations in the data. Delalande (1998) uses a similar research approach to that of Deliège (1989).

Delalande (1998) perceptual research study presents three types of listening behavior derived from analysis of listener responses data. This involves presenting participants with a piece of electroacoustic music and then interviewing each participant to identify their specific approach to listening. From the analysis of listener response data, Delalande identified three different listing behaviors: taxonomic, empathic and figurative listening (Delalande, 1998). Delalande and Deliège's studies identify the specific listening behaviors of participant listeners.

Bridger (1989) listener response study differs to that of Deliège (1989) and Delalande (1998) in that instead of defining listing behavior it attempts to formulate a terminology used to defined aspects of electroacoustic music. This involves the evaluation of the listener's perceptual responses with the objective of identifying common salient features (Bridger, 1989). Salient features as defined within this study, are the most common musical elements or characteristics perceived by participant when listening to works. The six most common salient features perceived by listeners were categorized into six "codes of significance". These "codes of significance" were used to construct a terminology for describing specific musical aspects perceived in the presented electroacoustic music (Bridger, 1989). Bridger's methodology is based on Roland Barthes' philosophical system of structural analysis. The listener response data was obtained through discussions with listener's participants. According to some, traditional music research practices employed in electroacoustic music research are not sufficient enough to respond to current inquiry and the application of other cross-disciplinary research methodologies is necessary (Truax, 1991; Weale, 2005) Bridger research study is an example of utilizing research methods from other disciplines.

According to Kendall (2007) electroacoustic music does not yet process a common language or notation format to describe different aspects of space. It is interesting to note that a recent study surveying composers points out that 62% of composers do not use any form of notation to document spatial aspects of their works (Peters, 2010). This indicates that more research is needed to formulate common terminologies and notational system for electroacoustic composers.

In general terms, I/R studies investigate the relationship between composer's compositional intentions and the degree to which listeners perceive these intentions. Weale's (2005) I/R study involves investigating the relationship between perceptual observations made by the listeners and that of the composer's compositional intentions in their electroacoustic works (Weale, 2005). This process involves presenting a work to participants a number of times. Information regarding the composer's compositional intention and objectives is given incrementally to participants each time they listen to the piece. The results of the study reveal: (i) aspects of the composer's intent are partially experience by the listeners when no information is provided, (ii) an enhanced or reinforced interpretation of the piece when the

title of the piece is provided, and (iii) knowledge of the composers intent was the most important factor with regard to enhancing the listening experience (Weale, 2005).

These studies identify listening behaviors, formulated categorization systems to create common terminologies and evaluated composer's intention in relation to listener perception. It has been mentioned earlier that electroacoustic composers to a large degree do not use a definitive vocabulary when describing aspects of electroacoustic music (Peters, 2010). The perceptual studies reviewed thus far do not identify how listeners perceive aspects of space or how aspects of space are composed. Could other perceptual research approaches be used to establish a common spatial terminology?

Ecological experimental design refers to experimental conditions that are the same or as close as possible to the real world environment in which they are attempting to represent. Sazdov *et al.* (2007) present an ecologically valid perceptual experiment for the purpose of constructing compositional techniques for electroacoustic music. This experimental design involves participant's perceptual evaluation of presented 2D and 3D multi-channel spatial scenes. Spatial attributes are used to evaluate the spatial scenes.

Result from the experiment identifies a unique 3D spatial attribute perceived by listeners. The attribute engulfment perceptual rating differs to that of envelopment when present on a loudspeaker configuration with elevated loudspeakers (Sazdov *et al.*, 2007).

According to Sazdov *et al.* (2007), engulfment is perceived as feeling covered over as opposed to being just enveloped or surrounded by sound. Participants rated the perception of engulfment significantly higher when the spatial scenes were presented on elevated loudspeakers when compared to presentation on horizontal loudspeakers only. Sazdov *et al.* (2007) conclude that the use of elevated loudspeakers contributes to the listening experience and hence presents the composer with extended compositional possibilities (Sazdov *et al.*, 2007). The use of the terms envelopment and engulfment are important to the current study, as they have been demonstrated to be perceptually real and present easily understood aspects of spatial music. According to Normandeau (2009), little is known about how space is perceived in a musical context or how musical gestures are perceived in space (Normandeau, 2009). Normandeau (2009) argues that perceptual research similar to that undertaken by Sazdov *et al.* (2007) is required to determine how space is perceived in an immersive environment (Normandeau, 2009). This study identifies how aspects of space are perceived by listeners and formulate compositional techniques from these observations.

Adaire *et al.* (2008) present an experimental study, which involves participants finding the optimal level of perceived envelopment within different excerpts of electroacoustic music (Adaire *et al.*, 2008). Data from the study shows the participants obtained comparable levels of envelopment (Adaire *et al.*, 2008). From the comparable data collected, the study identifies the technicalities of how envelopment can be achieved including specific loudspeaker configuration, stimuli and amplitude levels required. Sazdov and Adair's research studies like that of Weale utilized research methods developed from other field of research namely perceptual research in concert hall acoustics and reproduced audio research (Sazdov, 2007; Adaire, 2008). It is therefore proposed that an ecological valid experimental approach be used to formulate compositional techniques and identify aspects of space are perceived in multichannel electroacoustic music.

Review multi-channel diffusion systems

It is clear that the relationship between elevated sound and electroacoustic music was formed at an early stage. As mentioned above, Schaeffer and Henry were one of the first to present electroacoustic music through a configuration, which included elevated loudspeakers. Their tetrahedral configuration consisted of a frontal pair, a single rear and one elevated loudspeaker (Zvonar, 2004). The inclusion of an elevated loudspeaker suggests that Schaeffer and Henry considered the elevated placement of sound as having some compositional value. In 1970, at the Osaka International Exhibition in Japan, Stockhausen designed and presented music on a multi-channel configuration consisting of a sphere of loudspeakers. The sphere consisted of loudspeakers positioned at seven different levels located below and above the audience (Cott, 1973). A sense of "immersiveness" could be perceived when listening to music within this configuration (Normandeau, 2009). Emmerson (2007) categorizes Stockhausen design as "multi-loudspeaker immersion" (Emmerson, 2007). Stockhausen described the sonic experience as 'three-dimensional musical space travel' (Cott, 1973). The design and strategies created in this 3D diffusion system continue to inspire modern day large-scale diffusion systems. For example the Sound Dome of the ZKM is based on the design of the spherical auditorium of Osaka (Brümmer, 2011).

From the beginning of the 1970s onwards, a number of 3D sound diffusion system were established, most notably Gmebaphone (Clozier, 2001), Acousmonium (Bayle, 2007), Beast (Harrison, 1988), ZKM (ZKM, 2011) and SARC (SARC, 2011) and the dome located at University´ de Montreal (Normandeau, 2009). It is argued that new kinds of experiences can be perceived when listening to music within these configurations namely an immersive experience (Brümmer, 2011). The evidence would suggest that a perceptual sense of feeling immersed or enveloped in sound is associated with 3D multi-channel diffusion systems.

Composers perceptual observations

The majority of compositional research has concentrate on practical, theoretical or conceptual approaches to diffusion (Sazdov *et al.*, 2007). Composers such as Rolfe (1999), Wyatt (1999), Clozier (1997) and Harrison (1999) have presented articles that have discussed space in the form of engaging it through a theoretical application of diffusion. Rolfe (1999) observes that an "immersive reality" can be perceived when a sound is discreetly distributed to individual loudspeakers within an eight-channel configuration. Rolfe (1999) states that the space is undeniably more enveloping when presented on this 2D configuration (Rolfe, 1999).

Harrison (1999) outlines what he considers the minimum multi-channel loudspeaker configuration necessary for presentation of stereo electroacoustic works. The configuration is called the 'main eight' and consists of eight loudspeakers: a frontal stereo pair, a rear pair, a wide pair, and a distant pair. The distant pair is positioned behind the frontal pair at an elevated height of approximately 8 feet or above ear height. The rear pair is also positioned above ear height and is used to fill the space and add a sense of envelopment (Harrison, 1999). These observations are based on intuition and practical experimentation with various diffusion systems. Normandeau (2009) suggests that listeners should be able to move within the listening space so they become entirely "immersed" in the sound (Normandeau, 2009). This view of how a multi-channel electroacoustic music experience should be perceived is similar to what other composers have observed. For example Dhomont observes that music presented on large diffusion system (i.e. BEAST and Acousmonium) result in listeners being 'enveloped' and 'soaked in sound' (Basque & Watson, 2004).

As a result of their spatial flocking techniques, Davis and Rebelo (2005) state that sound 'envelops' the listener where by the listener becomes an "inhabiting agent" within the space (Davis & Rebelo, 2005). Wilson and Harrison (2010) report, a sense of diffuseness and/or increased physical volume as well as a "diffused but localized effect" can be perceived as a result of their swarm granulation techniques (Wilson & Harrison, 2010). The effects of spectral splitting, another spatial approach by Wilson and Harrison, reveals that sound material can be perceived as separating out too different locations within the multi-channel configuration (Wilson & Harrison, 2010). A summary of the expressive terms used by composers is compiled in table 1 below.

Expressive Terms	**Composer**
"Musical space travel" (Cott, 1973) "Immersion" (Emmerson, 2007) "Immersiveness" (Normandeau, 2009)	Karlheinz Stockhausen
"Immersive reality" (Rolfe, 1999)	Chris Rolfe
"Envelopment" (Harrison, 1999)	Jonty Harrison
"Move within" and "Immersed" (Normandeau, 2009)	Robert Normandeau
"Enveloped" and "Soaked in sound" (Basque & Watson, 2004)	Francis Dhomont
"Envelopes" (Davis & Rebelo, 2005)	Tom Davis
"Localized effect" and "Diffusivness" (Wilson & Harrison, 2010)	Scott Wilson and Jonty Harrison
"Immersiveness" (Peter *et al.*, 2010)	Nil Peters

Table 1. Composer's expressive terms

Conclusion

Many multi-channel diffusion centers have been established and have presented works by leading electroacoustic composers (Sazdov *et al.*, 2007). Even so, Peters (2010) research reveals that even thought there is a desire to engage with elevated sound, composers do not regularly do so (Peters, 2010). More importantly, Peters (2010) reports a low satisfaction rating given by composers with regard to their capacity to engage with elevated sound (Peters, 2010).

Why is there a lack of engagement in 3D space? A reason could be the limited access composers have to elevated loudspeakers configuration (Ontondo, 2008). Another reason could be that current techniques used to compose 3D sound are not successfully fulfilling the creative objectives of composers, resulting in a reluctant by composers to readily engage with elevated sound. This would suggest that there is a gap in understanding regarding how to effectively engage with elevated sound. It is argued that further research is needed to formulate spatial techniques to allow better engagement with elevated sound.

It can be concluded from observations made and expressive terms used by composers that the terms used most to describe multi-channel electroacoustic space are surroundness, immersiveness and envelopment. It is proposed that envelopment be investigated, as it is evident that it is the spatial aspect most associated with multi-channel electroacoustic music. Since it is argued that there is no universal vocabulary or terminology used to define or

describe aspects of space (Kendall, 2009; Normandeau, 2009; Sazdov *et al.*, 2007), it is proposed that terminology used in the related field of concert hall research and reproduced audio research be used to define the aspects of space observed and perceived by composers. It is argued that descriptive terms used in related disciplines can be used to define the spatial aspects, namely the spatial attribute of envelopment (Sazdov *et al.*, 2007). It is a widely used term in concert hall acoustics research (*i.e.* Ando & Kurihara, 1986; Barron, 1971; Barron & Marshall, 1981; Beranek, 1962; Barron, 2000; Blauert & Lindermann, 1986; Schroede *et al.*, 1974), as well as reproduced multi-channel audio research (*i.e.* Berg & Rumsey, 2000, 2001, 2002, 2003; Guastavino & Katz, 2004; Rumsey, 1998, 2002; Mason *et al.*, 2001; Soulodre *et al.*, 2002; Zacharov & Koivuniemi, 2001).

Finding from Peters *et al.* (2010) concludes that composers are most happy with their perception of "immersiveness". Considering that most composers are least happy with "elevated sound" and most happy with "immersiveness", this suggests that 'immersiveness' is a 2D attribute where as 'elevated sound' can be interpreted as being an independent 3D attribute. It is argued that a perceptually different spatial attribute from that of "immersiveness" can be perceived when engaging with elevated loudspeakers. A number of perceptual experiments undertaken by Sazdov (2008) have shown this to be perceptually real. The proposed spatial attribute of "engulfment" has been identified as describing the sensation of being "covered in sound|" and unique to sound presented from elevated loudspeakers, indicating that it is a unique 3D spatial attribute (Sazdov, 2008).

Further Research

It is proposed that perceptual research in the form of ecologically valid perceptual experiments (*i.e.* Sazdov *et al.*, 2007) be undertaken in order to formulate compositional techniques for multi-channel electroacoustic music. This novel research method involves the perceptual evaluation of 3D multi-channel electroacoustic music. This proposed ecological experimental research method is outlined the ICMC proceedings 2011 (Lynch & Sazdov, 2011).

Spatial Technique	**Loudspeaker configuration**
Timbre spatialization (Normandeau, 2009)	2D Horizontal
Spectral delays, Particle systems and Boids (Kim-Boyle, 2009)	2D (Stereo and Quad)
Frequency domain processing (Yorchia & Lippe, 2003)	2D (Stereo and Quad)
Spectral splitting (Wilson & Harrison, 2010)	3D (Tweeter trees)
Spatial swarm granulation (Wilson, 2008)	3D (Elevated loudspeakers)
Decorrelation (Kendall, 1995)	2D (Stereo)
Amplitude point-source panning (Wyatt, 1999)	2D (Discrete 8-channel system)

Table 2. Spatial techniques

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