2D AND 3D TIMBRAL SPATIALISATION: SPATIAL MOTION, IMMERSIVENESS, AND NOTIONS OF SPACE

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ABSTRACT

Timbral spatialisation is a signal processing technique that involves the spatial treatment of all individual spectral bands extracted from a source sound. Previous research proposed that Wave Terrain Synthesis can be used as an effective bridging control structure for timbral spatialisation, enabling gestural control of the thousands of panning parameters required [18]. This paper considers some possibilities and challenges of firstly establishing a spatial language for timbral spatialisation in live computer music, and follows by addressing problems and ideas in pertinent writings on the notion of space, spectromorphology, spatial motion, and immersiveness by Smalley, Wishart, Normandeau, Rumsey, Kendall, and Sazdov. This finally leads to a discussion of some possible immersive states created through timbral spatialisation, as well as the spatial movement generated by Wave Terrain Synthesis.

1. INTRODUCTION

Before the birth of electroacoustic music, space was not generally considered a primary parameter of compositional exploration for composers of Western Art Music, although we do see a few small exceptions in choral writing techniques such as antiphony and hocket, and orchestral techniques such as klangfarbenmelodie. With the advent of electroacoustic music came the possibility for composers to explore space as a significant musical parameter alongside pitch, rhythm and duration. Kendall explains that:

> "In electroacoustic music, the acoustic experience has often been a reference point, but the technology of electronic reproduction expands the scope and complexity of spatiality in a radical way. Even though the apparatus may be located within a physical space and even though our spatial hearing has developed within a physical world, electronic reproduction creates the potential for an art of spatiality."[2]

Acousmatic music, a form of electroacoustic music written specifically for loudspeakers, often involves spatiality as a primary compositional parameter, and as they are so inextricably linked to the notion of space the works can be highly compromised when removed from their intended spatial context [1].

Sound spatialisation in electroacoustic music practice is currently a diverse area of research with methodologies as various as DBAP[1], VBAP[2], ambisonic and binaural panning techniques, as well as wave field synthesis. Each of these methodologies addresses the notion of space psycho-acoustically through the use of localization cues, distance and azimuth. Some of the methods are generally more adaptable to various speaker configurations, such as VBAP, spatial decorrelation techniques, ambisonics, and spectral splitting [3]. Whilst timbral spatialisation has emerged recently as a distinct spatial methodology in its own right, it borrows from other existing panning theory, and differs only in that instead of a single point-source approach to a given sound, we have potentially thousands of different point-source locations active at any moment in time for each respective spectral band of a given source sound. The resulting effect is arguably more in line with Smalley's writing on *immersive space* and *circumspectral space* [4]. Normandeau goes on to state that timbral spatialisation recombines the entire spectrum of a sound virtually in the space of the concert hall, and is therefore not a conception of space that is added at the end of the composition process, an approach frequently seen, but a truly composed spatialisation; a musical parameter that is exclusive to acousmatic music [1].

2. THE NOTION OF SPACE

Denis Smalley points out that the term 'perspective' in the visual arts is a representation of three-dimensional forms on a two-dimensional surface articulating the relations of position, volume of occupancy, and distance as observed from a vantage point [4]. Smalley then goes on to define the 'perspectival space' of the acousmatic image as the relations of position, movement and scale among spectromorphologies, viewed from the listener's vantage point.

As Smalley himself writes:

> "Although there has been much value written about spatial attributes and the role of space, mainly by composers, the thinking is somewhat scattered, and as yet there is no substantial, unified text on the topic, nor any solid framework which might provide a

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[1] Distance-based amplitude panning
[2] Vector-based amplitude panning

reasonably secure basis for investigating space"[4].

Kendall also states that whilst the spatiality of acoustic music can be discussed in commonly understood terms, the spatiality of electroacoustic music still lacks a definitive vocabulary [2].

Normandeau explains that when a new medium appears – such as cinema, television, or the internet today – it borrows the language of the media from which it comes at before developing its own language [1]. In terms of the listening experience, timbral spatialisation is one such example that challenges traditional notions of spatialisation, such as point-source, as the kinds of movements that result from such a process do not easily conform with existing written taxonomies of spatial motion such as those found in Wishart's *On Sonic Art* [5]. Therefore, finding an appropriate vocabulary or range of descriptors seems to be necessary in order to re-define the scope of spatiality today. This is not exclusive to spatialisation techniques on the 2D plane, but also highly applicable to sound spatiality in 3D. Normandeau argues this as relevant for composers in order to establish and quantify the many compositional techniques attributable to electroacoustic music [1]. This includes the elevated plane:

> "Composers of electroacoustic music have engaged with elevated loudspeaker configurations since the first performances of these works in the 1950s. Currently, the majority of electroacoustic compositions continue to be presented with a horizontal loudspeaker configuration. Although human auditory perception is three dimensional, music composition has not adequately exploited the creative possibilities of the elevated dimension"[6].

More recently, perceptual research has been able to clarify a vocabulary, with special mention of the interrelated study of source width and listener envelopment [9,10]. Rumsey believes attributes of spatial sound should be unambiguous and uni-dimensional [11]. Deriving attributes from the framework of auditory scene analysis, Rumsey uses the three 'dimensional' attributes: width, distance, and depth. In addition, Kendall discusses the attributes of direction and height [12]. Rumsey defines envelopment and presence as two immersive attributes, and Sazdov further explores two further attributes: spatial clarity and engulfment [6]. This article will use these descriptors, and whilst the perceptive evaluation of these attributes is not the focus of this article, it is useful to note them as they will be useful in explaining and categorising some of the various movements timbral spatialisation creates.

Dimensional attributes	Immersive attributes
width	**envelopment**
depth	**engulfment**[1]
height	**presence**
distance	**spatial clarity**
direction	

Table 1. Spatial attributes as described by Rumsey, Kendall, and Sazdov et al.

3. SPECTROMORPHOLOGY

Out of the many approaches to spatialisation, timbral spatialisation focuses largely on the localization of spectra with respect to azimuth in the median plane. Early implementations of such a concept arose in some mono-to-stereo tools such as the Waves PS22 plugin. This plugin allows the user to shift the relative position of various frequency bands between two speakers resulting in a pseudo-stereo[2] effect.

Timbral spatialisation opens up the possibility of re-composing sounds in terms of timbre and space, and exploring this technique in a performative sense allows the performer-composer to explore concepts such as Ligeti's concept of *permeability*, where the individuality of timbre and interval give way to a more abstracted, chaotic, and increasingly complex texture [13]. Perhaps in the case of timbral spatialisation, we might refer to this as *spatial texture*. This research has focused largely on performances exploring the timbral spatialisation of live sampled input, allowing for a realtime acousmatic re-presentation of familiar sounds. As Smalley has written on spectromorphology:

> "The wide-open sonic world of electroacoustic music encourages imaginative and imagined extrinsic connections because of the variety and ambiguity of its materials, because of its reliance on the motion of colourful spectral energies, its emphasis on the acousmatic, and not least through its exploration of spatial perspective" [8].

Live acoustic performers may fall into what Rumsey outlines as dimensional attributes in relation to source, ensemble, room, and scene [11]. Yet discussions about timbral spatialisation are better adapted to immersive spatial attributes. Normally these attributes would describe specific sound sources, yet an exception is made when acoustic instruments are spatialised in a live environment, where different auditory scenes are put into conflict with one another. Kendall describes the following scenario:

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[1] Refer to Sazdov, R., G. Paine, and K. Stevens article. *Engulfment* is representative of the perceived experience of sound coming from above the audience.
[2] Such pseudostereo methods are discussed in Streicher, R. and F. A. Everest. 2006. *The New Stereo Soundbook: Third Edition*. TAB Books: Audio Engineering Associates, California.

"Imagine a situation in which a short performance on the cello is broken up into multiple frequency bands that are distributed among multiple loudspeakers. This is an example of a situation in which different categories of auditory cues are put into conflict with one another. There is one set of cues that leads the auditory system to form a single, fused sound image of the cello and other cues that suggest multiple images in multiple locations. The fusion of the image wins and the listener most probably perceives the sound event as emanating from an indistinct, but nonetheless singular, location."[12]

Barreiro reports a strong dependence on the input sound for the success of the technique:

"In general, sounds with a broad spectral content tend to sound diffused, providing an enveloping sonic image. Sounds with energy concentrated on specific regions of the spectrum, on the other hand, usually sound more localised" [24].

A focus on the spatial movement of broader spectra has become a focus of the authors research. The independent panning of singular bands is not enough to create movement that is meaningful or even audible in many instances, whereas spatial movement involve larger spectral densities are considerably more effective. Kendall suggests a number of workarounds to enhance spatial clarity in such instances, such as de-synchronizing the partials, or adding vibrato patterns on the individual components so that the human auditory system recognizes events in multiple locations.

A number of experiments with additional morphologies in live electroacoustic settings have been undertaken in works composed by the author Stuart James. In the live electoacoustic work *Particle 1* [26], frequencies that are not usually able to be heard acoustically are reinforced in two ruined cymbals– the fundamental frequency and lowest harmonics in the overtone series are captured by placing a pressure-gradient microphone 90° off-axis directed at the perimeter of both cymbals; refer to Figure 1. This overtone series is modified spectrally and granularly. In addition, the frequency is modulated, before finally passing through a process of timbral spatialisation. James also experimented with the spectral convolution of live recorded instruments in *The Talking Board* [27]. Here, mathematical operations such as spectral convolution using division (rather than multiplication) between live audio input and a graphic image file are used to change the spectral region and bandwidth, yet retain the textural and transient qualities of live recorded instruments; refer to Figure 2. These processed sounds were treated again with timbral spatialisation processes.
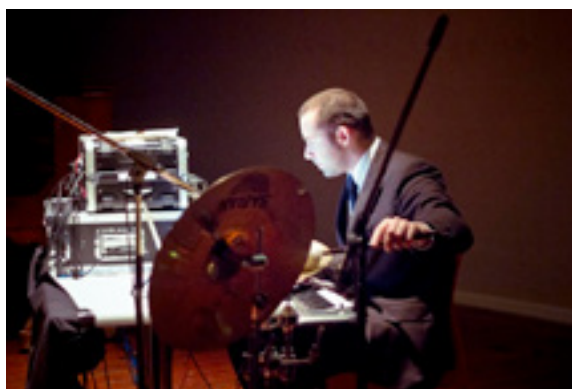
Figure 1. James performing *Particle I* during a Decibel ensemble concert at the Perth Institute Contemporary Arts in May 2011.
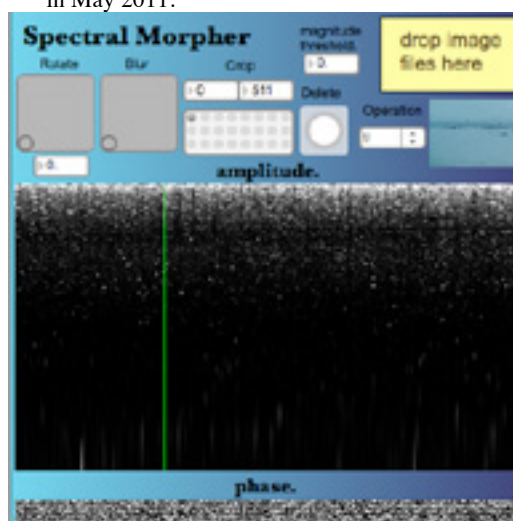
Figure 2. The spectral morphing MaxMSP abstraction created by James for *The Talking Board*.
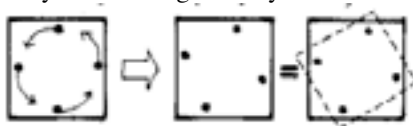
Control of timbral spatialisation has remained a problem due to the need to simultaneously manage several thousands of parameters found in the spectral domain [14], but there have been some elegant solutions to this using images and video [15,16,17,18]. Previous implementations of these solutions have employed the use of automated or pre-composed systems. These include the drawing of spatialization, or the feature analysis from other sound sources for spatial cross-synthesis. Building on the work of Torchia and Lippe in 2004, Kim-Boyle also used the Boids algorithm to determine the spatial location of each frequency band, and later simulated effects with the use of clouds of smoke [16]. More recently Barreiro has simplified the control of such a system by reducing the spectrum to eight frequency bands enabling a more static and simplified method of control [24].

Wave Terrain Synthesis may be used as a means of controlling timbral spatialisation, rendering such a complex processing system more manageable in live performance [18]. Wave Terrain Synthesis is traditionally a sound synthesis technique that involves the lookup of audio data from a 2-dimensional wave surface, although higher dimensional structures have also been previously investigated [32]. It is debatable that both the multi-dimensional, transformative, and

morphological nature of Wave Terrain Synthesis is synonymous with the transformations needed for controlling timbral spatialisation. Wave Terrain Synthesis is simple and effective to control, especially when mapped to a gestural controller input. Therefore using Wave Terrain Synthesis as a method of controlling timbral spatialisation allows a performer to sculpt the localisation of many individual frequency bands with a comparatively small number of control parameters [18]. Wave Terrain Symthesis' visual interface also enables a clear feedback mechanism for 'imagining' the sound and its movement through space.

Smalley's concept of perspective space, connecting timbral spatialisation with the visual arts, enables a conceptual alignment with the "painting" of colour onto a canvas – this canvas being representational of the sonic space. Certainly graphical sound synthesis methods such as Oramics [19] and Iannis Xenakis's Upic system [22] involve the drawing of sound in time. This concept has been extended into the digital domain with systems including Christopher Penrose's HyperUpic [20] and UI Software's Metasynth [21]. Eric Lyon has recently explored image-based spatialisation, where an image is used as a music score, providing the computer with detailed control information for spatialisation. Lyon makes the point that relatively little has been published on image-based spatialisation, and much of it is focused on automated mapping of video to space including the work of Shawn Greenlee and Augustine Leudar, a PhD candidate at SARC[1], who has worked with video to space in a quadraphonic context, using ambisonic tools for spatialization.[23]

The use of wave terrain synthesis as a control strategy differs from other systems in a number of ways. One is that the system is not fixed to haptic rate control as found with video, which is often restricted to below 30 frames per second. Instead wave terrain synthesis relies on two independent generative structures: the *terrain* and an audio rate *trajectory* signal; this allows for audio rate modulations. Secondly, it is not necessarily automated [18], and it can be easily controlled using gestural control. The rationale here for controlling timbral spatialisation with wave terrain synthesis was the ability to read spectral weighting curves from a multidimensional lookup table, and that certain geometrical distortions to the system might in fact correlate in effective linear and non-linear ways. For example, scene rotation, as seen in Figure 3, is not only easily created using this mapping strategy, but is also easily controlled gesturally.

Figure 3. The rotation of a scene as described pictorially in Wishart's *On Sonic Art*.

4.   SPATIAL MOTION

Perhaps what complicates the control of timbral spatialisation via wave terrain synthesis is the fact that there are two systems running concurrently, one a haptic rate dynamic system, and the other an audio rate dynamic system. Haptic rate dynamics created by the terrain are diverse resulting in rotating, fluttering, interweaving and interwoven spatial textures. Audio rate dynamics created by the trajectory result in a generalized feeling of inertia and momentum, and faster rate trajectories within the audible frequency spectrum tend to pulsate and finally become more enveloping and immersive. These phenomena complicate attempts to define a language of spatial motion for timbral spatialisation. So how do we define a language of spatial motion for timbral spatialisation?
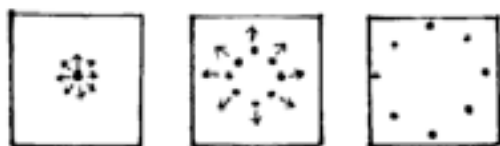
Wishart explains that the use of spatial localisation and motion of sound-objects provides the definition and transformation of musical landscape. Spatial motion may also be used to underline contrapuntal developments and interactions between different streams of acoustic sound. Wishart argues that certain sounds in the environment, like that of a fly, need spatial motion in order to be recognisable. Wishart suggests that more generally, we may look on spatial movements as musical gesture, and consider the typology and implications of different types of spatial gesture and how the spatial motion of one sound-object might relate to those of others. Wishart then proceeds to systematically document many of the known movements that may apply along the median plane. Rather than discussing curves of mathematical derivations, Wishart derives the semiotics of movement from the listener's experience, in order to settle on a visual language of spatial motion. Whilst these models refer largely to point-source approaches to spatialisation, they provide an invaluable aid in defining a scope of spatiality when we consider more recent signal processes such as timbral spatialisation.

The example of the fly conforms with the notion of point-source, however what happens when we have a chorus of cicadas? We are faced instead with many spatial points of reference, too many to be conscious of at any one time, so we start to listen to the chorus as one sound scene. There is still movement in this scene, as the cicadas' rhythms phase with one another creating a spatial shift in the sound scene. Most importantly the spatial movement is enhanced through the difference in time delays and directionality of each cicada.[2]
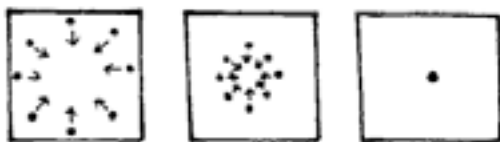
Whilst timbral spatialisation does not intrinsically involve time delays necessarily, we have a similar situation, with an addition of the fragmentation of spectra. If we were timbrally spatialising only three spectral bands, we would still be able to discern the spatial movement applied to each layer, although if we were to timbrally spatialise four thousand bands we would have difficulty discerning the spatial movement applied to each respectively. Rather we start to perceive the image as a single sound scene, and occasionally hear specific bands pass across the scene, giving the illusion of them passing across the listener[1], what Smalley describes as our egocentric space – the personal space, or within arm's reach of the listener [4]. How do we describe movements that are in fact complex 'compound' spatial motions? Pulsating, dispersed, correlated, uncorrelated, focussed or unfocussed? Might we refer to the results as examples of spatial textural movement?

One consideration with spatial motion is that the kinds of movements experienced in the point-source treatment of sounds are experienced very differently to the kinds of 'compound' motions experienced in immersive states. Given that the source is often a mono audio signal, one can expand and contract the frequency bands in space from a single point in space, and transforming this into an enveloping and immersive state, and similarly back to a single point again. This expansion and contraction can be visualised in figures 4 and 5. In this way, the performer has control over the perceived width, distance, direction, and immersiveness, including the nature of the spatial motion used in both Rumsey's definitions of dimensional state and immersive state. This spatial transition is primarily concerned with spatial width, so therefore it seemed appropriate to introduce a parameter that controls the expansion and contraction of the entire system. As Smalley describes, this affects the distal or proximate nature of various frequencies.

In many ways the trajectory movement found in wave terrain synthesis can be likened to the concept of the 'mobile' in sculpture. The mobile is a kind of kinetic sculpture constructed to take advantage of the principle of equilibrium. The meaning of the term 'mobile' has been suggested by Marcel Duchamp in 1931 to describe the early mechanized creations of Alexander Calder, and the reference has since been found in the music of Earle Browne, Morton Feldman, and Frank Zappa. As the trajectory is always in motion when using Wave Terrain Synthesis, the performer only needs to "modulate" or "disturb" this trajectory, effecting it in a way not dissimilar to a mobile's movement in air. In other words it becomes necessary to navigate these different states of the 'mobile' in a continuous way, so an interface for cross-fading between various states such as periodic, quasi-periodic, chaotic, and random trajectories became necessary; refer to Figure 7. These trajectories are all derived at audio-rate. Chaotic trajectories have been developed using *gen~* in MaxMSP as can be seen in Figure 6.

Figure 6. The rossler chaotic attractor built in gen~ by James, making use of the 1 sample delay

**Figure 4**. Wishart's diagram of spatial expansion (proximate to distal) [5]

Figure 5. Wishart's diagram of spatial contraction (distal to proximate) [5]
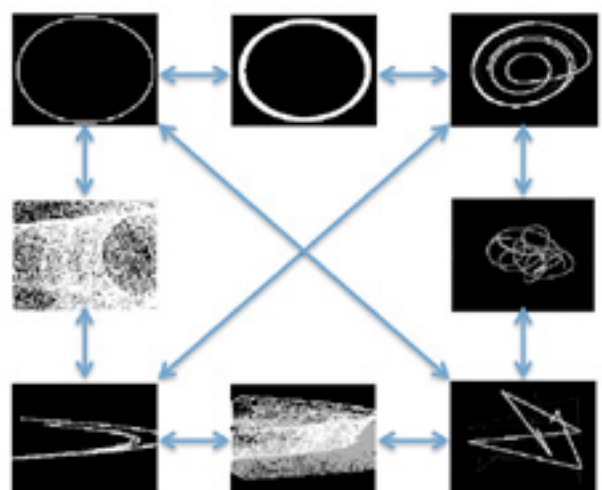
Figure 7. The trajectory state space, illustrating a smooth transition from a periodic motion, to quasi-periodic, chaotic, and random motions.

The opportunity to experiment with these techniques came up while developing the electronics component of Mace Francis's *Where Traffic Rises* [28]. Francis

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[1] In reality panning systems create auditory illusions of sound moving across space, however these are highly influenced by the proximity effect, i.e. whether the listener is equidistant from all loudspeakers.

created a stereo field recording of freeway traffic from the vantage point of a bridge, and needed this sound to be diffused in such a way that the car sounds moved independently of the general background ambient noise. By using spectral noise reduction software it was possible to separate the static spectrum of the original source from the moving and transient sound components; this can be seen in Figure 8. This process of separation allowed both sounds to be panned independently using a different kind of spatial motion: the vectorial spaces of the moving traffic and the panoramic space created by the background environment. The static components were dispersed randomly around the space, surrounding the audience, and the moving sounds were spatialised using translations across the space spectrally in a bidirectional way synonymous with the flow of traffic. This made part of a piece where acoustic instruments were also featured, furthering the need for a textural approach to the spatial motion.
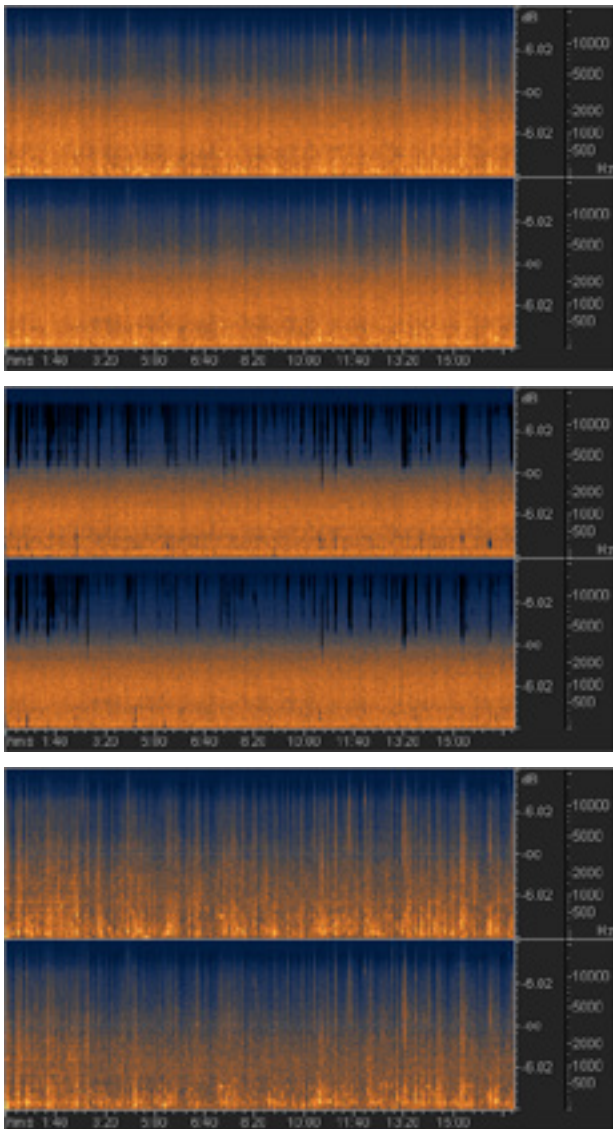
Figure 8. The spectrograms for the recording used in Francis' *When Traffic Rises*, showing a) the original field, b) the background noise, and c) moving/changing sounds respectively.

5. IMMERSION

"Always what was important to me was the notion of being immersed in enveloping space, and the sensation that you're fully enveloped,… it's not about interactivity but the fact that you are spatially encompassed and spatially surrounded—it's all around—and that's what sound is."[25]

Smalley explains that the 'perspectival space' can be regarded as the flux in relations among three views – prospective space, panoramic space and circumspace [4]. Prospective space is the frontal image, which extends laterally to create a panoramic space within the range of vision; circumspace – space around the listener – extends panoramic space to encompass the listener, with the possibility of approaching or passing over egocentric space from all directions. We are faced constantly by circumspace and immersive environments. One could consider the auditory scene on an aircraft: it is immersive in a sense that the entire scene we experience is in fact the aircraft itself resonating and vibrating, and this sound does not have one direction, we experience it as circumspace.

An opportunity to test the timbral spatialisation software in the SpADE[1] facility at DMARC[2], at the University of Limerick, Ireland, confirmed timbral spatialisation was an effective generalized method of sound diffusion, but more significantly the importance of the technique for simulating immersive and enveloping environments became apparent. Recent developments with the timbral spatialiser software also meant that navigating between various immersive states could be controlled easily and effectively.

Whilst the sound sources tested were limited to mono, the results were evolving, engaging, and immersive environments that completely surround the listener. These experiments involved varying degrees of random distribution of spectra across SpADE's 32-channel speaker array whilst experimenting with natural found sounds. Timbral spatialisation appears to be extremely effective in a 16-channel environment at creating immersive environments, be they artificial 'spaces'.
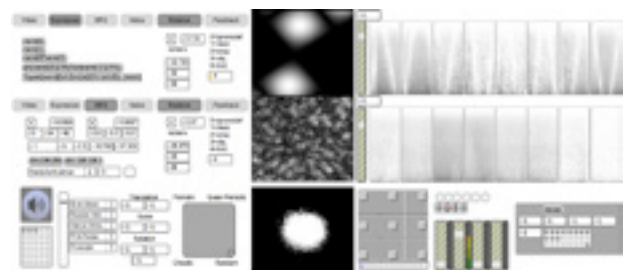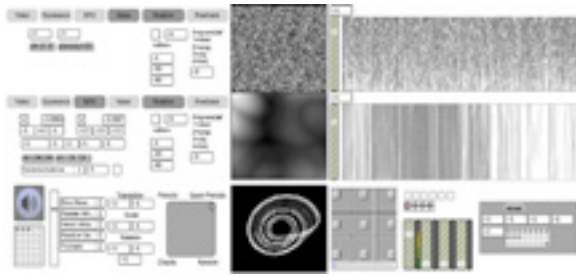
Figure 9. The 16-channel 3D timbral spatialiser designed by James. The two examples above show different states of terrain and trajectory motion.

These experiments led to establishing a current methodology that uses two different weighting systems that are convolved together, creating an "enhanced" spatial effect. Currently there are two models of this - one that collects information in a histogram and translates spectral distribution more accurately, and another that simply sorts the data biased toward high frequency resulting in another effective timbral distribution.

Transitioning from 2D to 3D timbral spatialisation involves another stage of convolution. In order for this convolution to remain sychronised it was necessary to perform this prior to the *pfft~* stage. The extra audio channels and jitter processing streams means the patch has become somewhat more processing intensive.
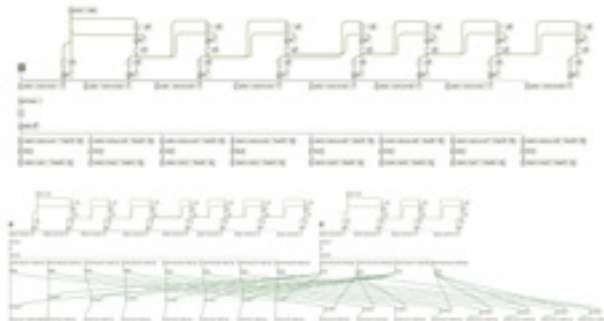
Figure 10. The MaxMSP abstraction responsible for sorting the spectral weighting functions.
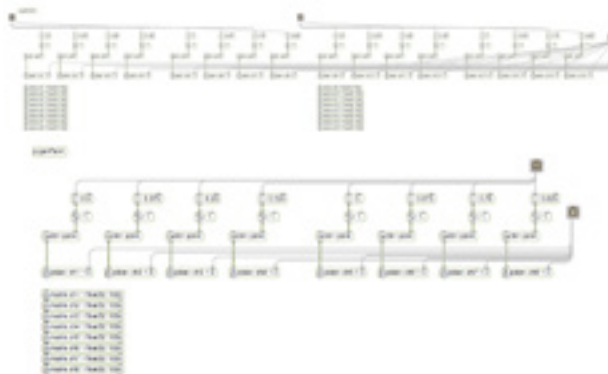
Figure 11. The MaxMSP abstraction responsible for reshaping the spectral weighting functions, with respect to the panning curve, and finally storing this to memory.

Veden Ja Tulen Elementit [29], or translated in English *The Elements of Water and Fire*, is a composition that began largely as an experiment in sound design, virtual immersive environments and spaces, developed whilst exploring a conscious fascination with the listening experience and various listening modes as discussed by Pierre Schaeffer (1977), Michel Chion (1983), Barry Truax, Katherine Norman (1996), David Huron (2002), and particularly Denis Smalley's discussions on space-form (2007). Two environmental source sounds, the sound of rippling river, and the sound of burning embers, were chosen to encourage a referential listening mode. The primary concern here was to gradually distort these sounds from their original associative references, and to push the listener from a referential listening state to what Pierre Schaeffer describes as the reduced listening mode [31], exploring various kinds of immersive states created through timbral spatialisation. The piece explores these immersive spatial attributes – envelopment, engulfment, presence, and spatial clarity using a variety of movements from slow circular correlated motion, sound slowly unfolding through space, slow fractal dispersion, to fast chaotic movement, and the random dispersion of sound. These contrasted and evolving *spatial textures* are explored with the intention of exploring different possible states of immersion.

6. CONCLUSION

Timbral spatialisation is a signal processing technique that has the potential for creating effective immersive spaces. However there still exists a lack of terminology for the kinds of spatial motion possible through such a system, and how this movement is perceived. With further reference to immersion perception theory it may be possible to clarify some further distinctions and definitions. This paper has been concerned primarily with the range of possible immersive states created through timbral spatialisation, and exploring the range of spatial movement generated by Wave Terrain Synthesis. Further research will explore the potential control of these immersive states using the iPad and Kinect as physical controllers. The research also involves a heavy emphasis on the writing of compositions exploring notions of immersive space.

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