Spatio-musical composition strategies

NATASHA BARRETT

Blåsbortvn, 10, 0873 Oslo, Norway
E-mail: natashab@notam02.no

Spatial elements in acousmatic music are inherent to the art form, in composition and in the projection of the music to the listener. But is it possible for spatial elements to be as important carriers of musical structure as the other aspects of sound? For a parameter to serve the requirements of musical development, it is necessary for that parameter to cover a range of perceptually different states. For 'space' to be more than a setting within which the main active elements in the structure unfold, it needs to satisfy these requirements. This paper explains a number of important spatial composition strategies available to the acousmatic composer in light of current technology and sound reproduction situations. The analysis takes an aesthetical rather than a technical standpoint.

1. INTRODUCTION

In acousmatic music, our real-time visual perception is not part of the listening experience. Without the sound's visual source to serve as a spatial reference point, the composer is free to manipulate the disposition of a sound-object[1] within a space, the space within which the object is sounding, and the relationships between objects, between spaces, and between object/space pairs. Under such conditions, from the point of view of the listener (where the composer is also a listener) it is necessary to piece together the complete sound picture. This picture consists of the combination of sound-objects and their spatial dispositions. Although we normally perceive the sound of the object and the space as a totality, for purposes of composition and analysis it is useful to separate the two.

When considering how one can transform spatial information to satisfy the requirements of structural development, it is interesting to first consider the importance of our spatial awareness. The perception of, and interaction with, our spatial world is vital to life. Our ability to control our physical activity depends on a spatial awareness. This spatial awareness is contingent upon muscular action and information received by our senses. Although we principally use sight, all our senses interact and support each other. For example, our judgement of speed would be inaccurate without aural cues. Hearing can also reveal spatial information when the eyes are useless: in the dark, when encountering a visual barrier, or when spatial information is outside our field of vision. Changes in temperature, humidity, touch and smell also contribute to our spatial awareness and spatial memory. When we re-visit spaces from our past it is the interaction of information from all our senses that evokes the memory – not only the immediacy of our vision.

Throughout our life we develop expectations that help us interpret our environment, and sound is one source of information we use to explain space. When we no longer hear distant sound through the roar of the traffic, we aurally re-define the expanse of the landscape. Imagine sitting in a quiet park, full of trees, bushes, flowers, birds, insects, a person kicking a ball, another walking a dog. The sounds around you give little clue to the expanse of the space, and visual obstacles gradually obscure the sight line. The park has a physical boundary fence, but no sonic boundary, and so the space extends beyond the fence in your *imagination*. Next, place a busy main road about 500 metres away. You can't see the road because it is obscured by trees and bushes, but the sound from the road now places a clear perimeter on our previously expansive idea of the space. Finally, overhead add a low flying helicopter and a more distant passenger plane. Although sound is not as directional as light, you are nevertheless completely enclosed within a sound space. The idea that our spatial sound environment and changes to that environment affect our psychology is not new. Attention can be drawn to Murray-Shafer's investigations of lo-fi and hi-hi sound environments (Murray-Shafer 1977), a body of psychology and health research dating from the 1970s, and more recently the work of Bechtel and Churchman (2002).

2. APPROACHES TO 'SPACE' IN MUSIC

2.1. Background: intrinsic and extrinsic identity

In a reductionist approach to electroacoustic music, there can be considered two main categories of material and structure: the intrinsic and the extrinsic. This holds true on all temporal scales, and when considering both the

[1]Although the term 'sound-object' is given different meanings in technical or aesthetic texts, it is here used to refer to a sound with a discrete spatial reference point, differentiated from the sound of the enclosure or resonator within which the object is sounding.

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isolated sound and the relationship between materials. The 'intrinsic' is the spectrum, its morphology, and the structural organisation concerning the spectral evolution solely as a series of frequencies and articulations, however complex. The 'extrinsic' is the sound's capacity to imply, to refer, or to associate with something other than that empirically present in the spectrum. Our memory plays with the 'extrinsic', bringing forth associations we have with the sound. Extrinsic and intrinsic properties are not mutually exclusive. They interact as our perception finds or loses connections through the act of listening. From an extrinsic standpoint, when neither source nor causality are clearly recognisable, we find ways to place the sound into the context of our knowledge of the world. Smalley refers to this as source-bonding (1997).

In considering sound identity, extrinsic links to sounding objects, to symbols or to gestural analogies can be investigated. Likewise, the listener can find extrinsic links to the spatial disposition of the object, the space in which the object is sounding, or the space in which we think the object *should* sound. These connections are derived from our perception of the sounding identity. The intrinsic aspects of the sound are clearly important in forming these extrinsic links, and will be returned to when discussing spatial transformation.

Four main approaches to space and how the composer can work with these ideas will be discussed:

(1) Illusion of a space or a spatial location of an object.
(2) Allusion to a space or a spatial location of an object.
(3) Simulation of the three-dimensional (3D) sound field.
(4) Spatial possibilities contingent upon temporal development.

The study concludes by assessing the role of the listeners' space in the transmission of spatial information by focusing on considerations of playback, sound reproduction and performance.

2.2. Spatial illusion

In the spatial illusion the perceived space appears real, but we are listening to an illusion in stereo or multichannel space produced through the phantom images from two or more loudspeakers. It is important to understand what happens to the sound-object in the *listeners*' space, but this will be returned to when considering the transmission of the sound to the listener. For now we can assume the listeners' space to be an acoustically dry, sound isolated studio.

Most aspects of the spatial illusion will be so familiar to acousmatic composers that they are taken for granted as compositional spatial devices. When working with a spatial illusion there are three main considerations:

(1) The nature of an enclosure can be indicated through an object sounding within the enclosure.
(2) The size of a space can be indicated through the relation between sounding objects.
(3) The size of a space can be indicated through the motion of sounding objects.

In all cases the *perceived* space appears real through maintaining real 'spatial laws'. These 'spatial laws' include:

(1) *The effect of sound transmission*. Although the effects of sound transmission include air absorption, diffraction and refraction of the source sound, the absorption coefficient (low-pass filtering of the source) is the only useable composition parameter. This is because diffraction and refraction are perceptually understood only when the listener is aware of the *real* location of the source and has knowledge of the meteorological conditions in the environment.
(2) *The properties of the reverberant field*. Clues to the characteristics of the space are provided by surface reflections forming the reverberant field. Clues to the proximity of the sound to the listener are gained from the mixture of early and late reflections, and from the mixture of the direct and reverberant field combined with low-pass filter characteristics. For information on sound transmission and room acoustics, numerous references are available. For a simple guide, see Rossing (1990: 457–92).
(3) *Object image size and multiple object relationships*. The closer the sound-object to the listener, the larger its perceived sound image. Therefore, image sizes give a good clue to the proximity of sound-objects in relation to each other, as well as in relation to the listener. This holds true regardless of whether one considers the characteristics of the enclosure. When the source of the sound is unmistakable, the physical size of the sound is known, and this knowledge puts restrictions on compositional image size distortions.
(4) *Doppler shifts and gestural-spatial definition*. The motion of a sound-object is the main clue to the size of an enclosure if the enclosure is non-resonant (for example an anechoic chamber or an acoustically transparent cage). The perceived spatial coverage, and therefore the minimum size of the enclosure, are strongly linked to speed, gesture, and Doppler shifts. This is particularly true when considering a gesturally defined spatial illusion in the stereo field where Doppler features and filtering effects provide clues to front–back motion and the illusion of frontal depth. Some compositionally interesting spatial gestures are described by Smalley (1986: 90; 1997).

Most spatial illusions depend on *one or more* of these four aspects, whether the sound-object is *recognisable* or *abstract*. It is relevant to add two technical notes:

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(a) The width of spatial illusion in the listening space will partly depend on the width of the loudspeakers in relation to the listening position. However, in many cases, as the listener moves out of the ideal listening position, the phantom image, and therefore the illusion, will partly break down.
(b) Because our aural perception can locate higher frequencies and texturally varying material more easily than lower frequencies and static material, the intrinsic nature of the sound will play an important part in the composer's choice of material.

Example 1 is a close microphone recording of resonant clock chimes. The sound is recorded without any suggestion of space apart from the size of the sound-image suggesting close proximity to the listener (or in fact to the microphones). The resonance is that of the sound-object, not of the space in which the object is sounding. In fact, in listening to this example the object is sounding only in your listening space. In example 2, a reverberation effect is added to the sound-object giving the illusion of the object sounding within a large enclosure. In addition to the reverberant field and low-pass filtering of the source, the sound-object's image size has been reduced.

Example 3 illustrates how an enclosure can be defined by gesture and motion. In this example, the width of the spatial illusion is strongly linked to the position of the loudspeakers in the listening space. Example 4 is the opening of the work *Angels & Devils* (Barrett 2002). The example illustrates how relationships between multiple objects, in combination with spatial gesture and the reverberant field, can together unfold the (changing) illusion of space through time. Features of the spatial illusion (combined to some extent with features of spatial allusion discussed below) can be found in whole or part in most acousmatic works. For specific listening the reader is referred to established repertoire such as Dhomont (1989) and Harrison (1982).

2.2.1. Robustness of the spatial illusion

A spatial illusion does not need to satisfy all of the real spatial laws. In fact it is interesting how much one can get away with before the perception of a spatial illusion breaks down. A primitive reverberation effect can provide the illusion of a spatial enclosure, particularly if other spatial factors such as filtering and amplitude relationships between source and reverberant field confirm our perceptual decision. We know the illusion does not *exactly* resemble a real-world image, but nevertheless accept the information as a good enough approximation. This robust aspect of our spatial perception means that we can use techniques such as time stretching, delays, resonant filtering and granulation in an attempt to create an illusion of space, all of which serve to smear, prolong or filter the sound in a similar way as the different components of the reverberant field. The composer can then consider the point at which the illusion of space breaks down and what the resultant sound will imply.

Example 5 is a recording of a man shouting into a piano. The resonance added to the sound-object (the man shouting) is that of the piano strings and piano structure, and approximates to the reverberation effect. In this example, recognition of the source is important to separate the identity of the object from the resonance of the piano. Without source recognition, because some of the illusion cues are missing, the differentiation between an object sounding in a space and a single resonant sound-object will be less apparent.

Examples 6 and 7 illustrate two different types of resonant filtering. Are we hearing a poor reverberation simulation of a small resonant enclosure, or is the resonance part of the sound-object itself? Clear recognition of the source means that the resonance cannot be part of the object itself, but at the same time the result is distant from any real-world spatial illusion. In reducing adherence to the spatial laws there will come a point where the spatial illusion breaks down. In such situations we either lose all spatial implication, or find a spatial link through a spatial allusion.

2.3. Spatial allusion

When space is implied without a direct illusion, or without a direct connection to the interrelated acoustic laws of objects sounding in spaces, we can begin to discuss the spatial allusion. Under such situations the 'listening imagination' is important: composers need to make assumptions concerning aural interpretation, and listeners have a more active role in the experience. Because the spatial allusion is open to interpretation more than the spatial illusion (due to its images being less precise), it is maybe here that the 'music' begins to emerge. The transformation from illusion to allusion is therefore an important spatial developmental process.

Through allusion, space can be implied by:

(1) information other than the spatial laws, and
(2) information that does not conform to the spatial laws, where insufficient spatial laws are present, or where presented spatial laws are set in conflict.

2.3.1. Information other than the spatial laws: the potential of the immediate source-bond

The discussion of illusion did not consider the nature of the source or the source-bond. On hearing a sound that we recognise, or a sound to which we think we have found a clear source-bond, we place it within a space that is appropriate, whether or not that space is actually 'sounding'. For example, the sounding result of wind swaying a large tree in full leaf is often identifiable (or

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at least we think we identify the source), and we will therefore automatically assume an outdoor space. On an abstract level, a constantly changing noise-based granulated texture of a low volume may imply natural sound sources, which in turn will imply an outdoor, open space. We must also not forget that the position of the sound in a space affects the connotations of that sound. Changing the position may change the connotations (a distant car has very different connotations than a car passing one metre away from the listener).

For a symbolic approach to space, Wishart's ideas of extra-musical landscapes (1986) are an ideal reference point. Although Wishart discusses the idea of gesture and how it can develop over time, the symbol of the sound object – its identity regardless of its gestural flow – is important to the construction or deconstruction of a sonic landscape. One can extend this thinking to include spatial information: as having an identity derived from a symbol, or from a surrogate of a symbol, rather than necessarily from the gestural activity of objects sounding within the space. Although example 8 is a transformed sound recording, the potential of the immediate source-bond suggests an outdoor space: a concrete or stone floor, footsteps, possibly surrounded by trees being blown by the wind. Implications of the 3D sound field for the perception and composition of the sonic landscape are discussed later.

The combination of spatial allusion and spatial illusion is commonly found in acousmatic music. In example 9 we hear the combination of real spatial laws and the potential of the immediate source-bond: the sound-objects are set in positional relationships within the stereo picture, but the totality of the picture suggests an allusion to a total space within which the objects are sounding.

Even if the material does not suggest a direct source-bond, a space can be alluded to. Unlike the illusion of space, which can be precise regardless of the clarity of the sound-object's identity, the allusion of space is tightly linked to the source-bond. If the sound object suggests a remote link to some sounding identity or sounding gesture, the spatial implication linked to that source will be similarly remote and open to interpretation. In example 9, the source-bond is relatively clear, and likewise is the allusion to a space. In example 10 the material has no direct source-bond and only vague spatial illusion cues. Nevertheless, the allusion to a spatial setting is an important part of the sound-picture – traced through morphology in the stratified sound layers. But due to the remoteness of the sound identity and gestural activity, this allusion can be heard in numerous ways.

2.3.2. The path to non-sounding real-world spatial implications

A non-sounding spatial analogy is a musical-spatial implication without a real-world *sounding* counterpart. Non-sounding real-world spatial implications come from touch, smell and sight, as well as non-sounding gestural activity (which has a visual or a muscular gestural counterpart). Removed from the musical context, non-sounding spatial implications are difficult to understand. Within the context of the work, the non-sounding analogy can gain clarity through contexts that unfold over time. The manipulation of spectral materials has often been described as a manipulation of 'spectral space', and this connects to visual space. For example, in Smalley's discussion of spectral grounds and canopies (1997) one can find a clear analogy to a visual space. The spectral root is the floor, the canopy is the roof, and these define an enclosure within which objects can exist. The object is not sounding within a space in an acoustic sense, but placed inside the sounding analogy to a visual space. Spectral space is sometimes discussed in relation to instrumental music (most prominently in connection to the music of Tristan Murail) but without connection to the visual analogy. In the context of instrumental performance, the identity of the sound's source is undebatable and distracts from any potential visual spatial connection.

Visual analogies are maybe the most common non-sounding analogies. Although, as Bachelard says, '. . . sight curtails the dramas it witnesses. But a whiff of perfume, or even the slightest odour can create an entire environment in the world of the imagination' (1994: 174), our memories of space through touch and smell are maybe too personal to communicate through a direct musical allusion. An informative programme note can be a useful aid. In other cases it is more likely that a sound in the music would evoke a spatial setting, and that setting in turn imply or incorporate a non-sounding spatial link. One can regard this as a secondary allusion. Here the idea of the tactile or olfactory memories are not directly found in the music, but instead are linked to the music via the sounding link to the real-world setting. In other words, the totality of the spatial connection includes smell, touch, sight and sound, even though the primary path to that space may have been solely aural. For some sonic archetypes, many listeners may experience this indirect non-sounding analogy similarly. Take, for example, the first part of Luc Ferrari's *Presque rien no. 2* (1977). The attentive listener is transported into the space of the music. This space is clearly a 'sounding' space, but for some listeners it can also evoke connotations of temperature, light and humidity associated with the complete environment – the interpretation of which is extremely personal.

2.3.3. Spatial occupation

A sound mass, through density, texture and amplitude, can suggest a volume of space through *implied* spatial occupation. Reverberant aspects of the enclosure are an

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unnecessary part of the spatial picture. In this way, spatial occupation can be regarded as a step further from gesturally defined space and from multiple object relationships explained under spatial illusion. It is tempting to categorise spatial occupation as a type of spatial illusion. However, the clarity of the spatial implication is open to significant interpretation, and for this reason it is categorised as a spatial allusion. In example 11, small sound-objects are combined with a resonant drone suggesting some kind of enclosure. Gradually the materials accumulate to create a sense of space through their spatial occupation. The transformation of gestural spatial motion or multiple object relationships into implied spatial occupation can be used to connect a spatial illusion and a spatial allusion.

2.4. Three-dimensional sound fields and spatial continuums

Recent experiments show that it is possible to create a virtual sound field within which our aural perception is as accurate in locating a source as in the real sound field (Martin, McAnally and Senova 2001). Such accuracy of virtual sound fields was achieved using headphones, and systems with similar accuracy in sound field reproduction over loudspeakers are currently unavailable. Nevertheless, manipulation of the virtual 3D spatial continuum is becoming more relevant to the composer as new technologies emerge.

The required spatial resolution and spatial accuracy in the virtual 3D sound field will partly depend on the application. When producing documentary 3D sound recordings (which may also be a part of a composed work) the sound field needs to mimic reality such that departure from reality is below our perceptual threshold (such an audio reproduction system was described as reality-mimicking by Malham 2001). Blauert (2001) presents an investigation of this perceptual threshold and the associated hearing mechanisms. When working with non-documentary sound fields in a composition, the requirements change. From a cognitive rather than physiological or psychoacoustical point of view, and particularly in relation to the previous discussion on the importance of sound identity in the spatial allusion, we can *assess* spatial information in the virtual field in two ways: (i) by associating sound identity with the discrete location we believe the sound should have in relation to reality, (ii) by comparing spatially different materials and drawing on their spatial relationships. The relationships between spatial objects rather than their discrete spatial position then gain in importance, especially when *direct* sound identity may be of less importance in the music. Therefore the composer can 'get away with' less accurate discrete spatial locations as long as the object relationships are maintained. Images can be rotated, and sizes and distances distorted without significant disturbance to the musical landscape, as long as the relationships remain stable.

In the synthesised 3D sound field one can enhance spatial clarity by reducing confusing factors found in reality. Such enhancements include amplitude and spectral changes of specific aspects of the sound field (regularly practised in conventional sound recording techniques by mixing spot-microphone sources into the main stereo picture).

The author's work in the composed 3D field has focused on the use of ambisonics techniques. Ambisonics encoding attempts to preserve spatial information, and this information is decoded over a chosen loudspeaker array. For a technical explanation of ambisonics, see Malham and Myatt (1995). A number of ambisonic sound examples related to the following text are available over the Internet.

2.5. Differences between composing in the stereo and the 3D field

Composers often think about 3D information even when realising ideas in the stereo field. The lack of real 3D sound control becomes more apparent when the work is taken out of the studio (described as control room monitoring in Roads 1996: 377). When composing in the full 3D field the basic ideas of illusion and allusion are maintained, as are the ways one goes about realising these ideas in the sound material. The differences between composing in the stereo and the 3D field can be grouped into three categories: (i) technical differences, (ii) issues of clarification in spatial information, and (iii) additional compositional considerations.

2.5.1. Technical differences

The technical aspect of the mixing and sound transformation process

Working with ambisonics is a two-way process of encoding and decoding. Therefore, the composer is required to mix encoded spatial information and decode in real time, or encode and decode in real time. In most cases, sound transformations need to be carried out before the material is spatially positioned. This is because the transformation will often destroy the encoded space. In some situations, sound transformation can incorporate the encoding process, for example granulation, where each grain has a 3D spatial location (Barrett and Hammer 2002).

The technical aspect of sound reproduction

Loudspeakers need to be carefully chosen, matched, and in the positions specified when the music is decoded. Departure from these specifications will distort the sound field. Ambisonics assumes that the loudspeaker is a point source, whereas most high-quality loudspeakers consist of separate speaker elements. The author has found that small, compact speakers recreate a marginally more accurate sound field than physically larger

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speakers. However, it appears more important to ensure equal volume, spectral balance and accurate physical location of each loudspeaker.

2.5.2. Clarification or preservation of the composed space

Spatial ideas applied in the stereo field are often lost outside the studio. If these ideas are instead realised in the 3D field, they are more clearly projected to the listener. This clarification includes the sound location, gestural spatial definition, a clearer layout of 'landscapes' (real or surreal) and distortions of the landscape, and a clearer presentation of object and spatial relationships in the spatial illusion and allusion. The capacity to allude to a spatial resonance also becomes more apparent due to the listener's complete immersion in the sound field.

In performance it is possible to reproduce a spatial-gestural counterpoint featuring multiple independent motion trajectories. Independent motion is a feature of the real world as much as correlated motion, but is tricky to project in a concert hall via traditional sound diffusion of the stereo field. Whether the material is intended to be equivalent to reality or only imply some aspects of reality, the creation of independent motion gestures will be clearer and therefore allow new exploration of the composed space.

2.5.3. Compositional considerations more apparent in the full 3D field

An increase in the number of simultaneously perceptually identifiable sounds

Spatial hearing involving multiple sound sources has to some extent been investigated by Blauert (2001). These investigations provide insight, but because the test data consists of pure tones, the results are detached from the physical world. Although no clear experiments have been carried out to test the limits of our perception of complex multiple sound sources, there are some guidelines. Spatial separation is one of these guidelines (in addition to avoiding frequency masking and maintaining some temporal-textural difference between simultaneous sounds). In the 3D field the increased number of simultaneously perceptually identifiable sounds allows the composer a richer counterpoint in both spatial and non-spatial terms.

In example 12a, eight continuous sounds play simultaneously at static points in space. The example attempts to avoid significant temporal-textural variation or silent gaps within the sounds, while allowing some spectral masking. From the eight simultaneous sounds, five will be heard by the average listener. In example 12b the same material is slowly moved through the space. It is interesting to note that the spatial motion further separates the material and increases the number of perceived sounds. Examples 12a and b can be set in contrast to example 13 in which the same information is decoded for the stereo field.

A more intimate relationship to the listener through sound proximity

In a 3D virtual sound field, the origin of the sound can appear to be closer to the listener than the point of the loudspeaker. This means that the composer can work with more intimate sound proximities and also enlarge the spatial difference between distant and near sound materials. The effect of decreasing the apparent spatial difference between the sound location and the listener creates a tighter bond to the listener's physical space.

A convincing reproduction of real-world sound environments

The requirements for a convincing reproduction of a real-world sound environment were briefly discussed above. From a compositional point of view one can regard sound development as limited by the extremities of a possible sound transformation. If the transformations are based on the distortion of real-world images, a starting point closer to reality will expand the extremities of the transformation. Traditionally, acousmatic composers have attempted to find a foothold in reality through high-quality sound recordings. Using reality-mimicking source sounds and playback systems can be seen as an extension of this technique.

No interpretation in performance

Skilled sound diffusion performance (the projection of the stereo field over many loudspeakers) can turn a mediocre piece into something more interesting, simply through the performed enhancement of contrast, transparency and spatial-gestural dynamics. Without this last stage in the process of the music arriving at the listeners' ear, composers' responsibility towards their music increases. Removal of spatialisation interpretation may appear trivial, but as most regular performers of stereo tape music will know, the music can sound significantly different depending on how it is performed.

Exchange of spatial identity

Common transformation techniques for musical development include the exchange of temporal and spectral information between materials (different types of cross synthesis involving frequency, phase and amplitude). Spatial identity can likewise be transferred between materials, and when perceptually clear, I will refer to this as 'spatial mimicry'. Spatial mimicry is useful in forming a spatial-structural bond between sound materials and their intrinsic and extrinsic implications. The conditions under which spatial mimicry is successful are few. When an object is connected to an illusion or even an allusion of space, true spatial mimicry is problematic in the stereo field: (i) because of the tight bond between the identity of each individual source and its spatial implication, and (ii) because clear spatial mimicry in the stereo field is often confined to left-right panning. In the 3D

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sound field, spatial mimicry is more viable because the physical presence of the sound in relation to the listener is strengthened, and can therefore compete with the source-bond aspects. Nevertheless, the effect is most successful when the sound-object does not suggest a strong spatial bond through its sound identity. Examples 14a, b and c are three different source sounds spatialised by the same process. The spatial mimicry and spatial segmentation produce a clear link between the material. For a complete music context the reader is referred to the complete work (Barrett 2002).

Our perception of the 3D composed sound field and compositional consequences

At present we are not used to hearing impossible spatial motions and sounds with indirect source-bonds in the continuous 3D sound field. Spatial information in acousmatic music has previously been confined to the stereo or diffused sound field, or to the use of loudspeakers as point sources. High quality 3D sound reproduction can convince our aural perception that the composed space has qualities on a par with a real space, whether or not it is reality-mimicking as described above. Despite the departure from reality in the sound-object, spatial disposition and motion finds connection to reality. Even if this spatial link is through a remote gestural bond, the direct connection to our 3D physical space in unavoidable. Unlike in the stereo space, we are convinced to accept what was previously 'surreal' as real. The ability to perceive information in this way is not immediate for all listeners. We do not use our aural spatial perception every day as much as our ancestors would have done for survival, and our spatial awareness requires some training. Even participants of aural spatial perception tests go through an aural-spatial 'training' period before the tests are carried out (Martin, McAnally and Senova 2001). But once this skill has been acquired, a 3D spatial awareness is difficult to lose. When impossible spatial motions and sounds with indirect source-bonds in the 3D field are accepted as having reality qualities, a number of new spatial composition devices become evident. The spatial reality within the listening space can persuade us that there is a connection to the real world – and that *we have simply never experienced the presented scenario*.

The sound-object spatial setting: consonance and conflict in the 3D sound field

The use of sound symbols and sound identities in the creation of acousmatic landscapes is described in depth by Wishart (1985). An acousmatic landscape involves the juxtaposition of sound-objects that together produce an identity for the landscape. By presenting impossible juxtapositions of sound identities, or in other words conflicts in object identities, the composer can begin to work with a surreal landscape, accepted by the listener as unreal. When manipulating sound in the 3D field, the perception of the surreal landscape is somewhat different. In a non-documentary musical context, the mixture of conflicting identities in the stereo field is simply a confusion of reality and fantasy. Resolution of the stereo field is inadequate for displaying clear spatial information conflicts. We will perceive any conflict in spatial information as simply a departure from reality, in keeping with normal sound transformation techniques. In other words, non-documentary acousmatic material is a departure from reality, and any further departure on spatial grounds is accepted as normal in that context.

To explain how spatial consonance and conflict are possible in the 3D field, one needs to consider the nature of different sound-objects and sound-spaces, and the link to 3D physical space. The nature of different sound-spaces (composed spaces and listening spaces) has already been discussed.

For a sound-object to appear to have a real-world source it does not necessarily require a clear source-bond. Appearing as if produced by a resonating body or volume of air, with life-like temporal variation, is often enough. Such sound is characterised by attention to small details, irregularities, instability and change in spectral evolution – qualities difficult to synthesise manually, and easily upset by spectral transformation. From this standpoint one can regard a synthetic sound as sound lacking qualities of the real sound. The border between real and synthetic is naturally blurred and will depend on the sounding context. Nevertheless, within a given context some judgement can be made.

Maximal consonance

When there is no conflict of spatial information in the 3D space we can define a state of maximum consonance. Such conditions arise when:

(1) 'Real' sound is placed in an expected spatial setting. An 'expected' setting is implied from the sound-object's identity in combination with a spatial illusion.
(2) Synthetic sound is placed in the listener's space. When the sound-object lacks extrinsic links and there is no effect of enclosure to imply a spatial illusion, in the listener's space the only relevant spatial information comes from the location of the sound in that space.

Maximum conflict

A state of conflict will arise where the spatial information inherent to each sound-object is conflicting with their 3D spatial dispositions. Conflict can arise when opposing spatial allusions are juxtaposed, even though the material may conform to the same spatial illusion. The 3D spatial clarity prevents the opposing allusions collapsing into one single allusion or even departing into a new realm of fantasy.

It is difficult, on the other hand, to create a conflict of spatial illusions. Illusion cues from many objects sum together to produce one total spatial illusion. For

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example, the size of space perceived from the combination of a rapidly moving gesture and a stationary point will be the product of the spatial extremes defined by each sound. Likewise, a juxtaposition of different reverberant fields will collapse into one rather than present a conflict, simply due to masking effects of common intrinsic information.[2]

3. FEATURES UNIQUE TO THE TEMPORAL DOMAIN

Sound transformation and mixing techniques allow the composer to move freely through the described aspects of spatial illusion and allusion. When considering temporal development more closely, further considerations are apparent.

Memory for spatial information

In contemporary instrumental music, memory for pitch, rhythm, and to some extent timbral motifs is trained through the course of listening to the specific work. New motifs are presented and developed for each piece of music, and the listener needs to remember this development to appreciate the structure of the work. In contrast, the listener's spatial perceptions can be linked to an experience of the world outside the context of the music: the perception of spatial information exists through our connecting it to real-world experience, drawing on the contents of long-term memory, whether through illusion or allusion cues. Although clearest memories may be retrieved when hearing recognisable sound-objects and direct spatial relationships, spatial memories may also be evoked through less direct sound identities and motion characteristics.

However, when the composer transforms or collages spatial information in the composition, the *temporal transformation* may easily depart from any real-world temporal experience. In this case the spatial information presented over time can be unique to the context of that particular work, and therefore require listeners to train their memory through the act of listening. Thus the composer can choose whether to draw on existing long-term memories, or challenge the listener with unique information. In other words, the composer can combine self-referential and outer-referential developments.

3.1. Motion through time and space

It is intuitively understood that an increased speed (implied most prominently by amplitude and Doppler cues), and constant duration of motion, will suggest an increase in the distance moved. But what happens in the virtual 3D sound field if the physical speed is slightly changed, while the spectral cues remain constant? Small decorrelations in physical speed and spectral cues will often go unnoticed. But larger changes will result in a paradox. If physical speed is decreased while the synthesised Doppler pitch shift occurs at the same point in the duration of the sound, the Doppler shift will be heard before the sound has moved past the listener's real position. A similar situation arises when amplitude varies at the wrong point in space in relation to the listener. Under these conditions, if the spatial synthesis is imprecise, the listener may experience a front–back or left–right confusion and a breakdown of the 3D space (which may be intentional). If the spatial synthesis is accurate, it is more likely that the sound object will appear to have undergone a transformation. If, on the other hand, spectral changes occur at the correct point in space, yet remain of the same magnitude after a change in physical speed, it is unlikely that the spatial synthesis will break down even though there is a departure from real motion laws. This is due to the strength of the correct physical relationship to the listener overriding discrepancies in the spectrum–speed correlation. In example 15a, two similar sounds move rapidly through the space (and fuse partly into one single moving sound). The Doppler effect is clearly apparent, and is heard at the correct point in space. In example 15b, the Doppler shift is repositioned to occur at an incorrect position. In example 15c the real speed is decreased while maintaining the original dynamics of Doppler information, and with that information placed at the correct point in space.

3.2. The implication of space without a sounding object, and transformation from an object to a spatial resonance

A sustained sound, lacking significant spectral or volume dynamics, not appearing from a single point in space (e.g. projected via uncorrelated playback channels), can be interpreted in many ways. It cannot be heard as an illusion because no sound-object is present to stimulate the reverberation. However, with the addition of 'foreground' sound material the spatial allusion of some strange reverberant field may be apparent. If the foreground material is unrelated spectrally and temporally to the sustained sound, then it could not have stimulated the resonance, and likewise will not be interpreted as a direct spatial illusion. In example 16 we hear a continuous sound with no clear spatial implication. In example 17, the material from example 16 is overlaid by a nearer sound field, and although these sounds are not stimulating the rear sound field, the spatial allusion is apparent. In the 3D sound field the result is further apparent due to the listener being enclosed by the resonance.

In the temporal context, by transforming the *intrinsic* properties of a sound one can change the *extrinsic* link from that of an object to that of the resonator or enclosure. This relationship between the sound-object and the

[2]An illustrative sound example is too lengthy to include in this paper, and the reader is referred to the work *Prince Prospero's Party*, 2′00–9′00 (Barrett 2002).

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sounding enclosure is essentially similar to the real-world relationship between a sound-object and the reverberant field. Example 18 illustrates a number of steps in the transformation of a church bell to a spatially vague pitched drone. The strongest link between the 'bell' and the drone is the spectrum. In addition, some temporal information is maintained. When considering this process as a continuous sound transformation, we can say that the spectrum is the pivot point between the perception of a sound as an object and the perception of a sound as a spatial resonance. Although in example 18 the result of the process is a spatially vague drone, the addition of sound-objects in the foreground of the picture will clarify the spatial implication. Amongst other sounds, example 19 contains a continuous transformation of a bell sound. The bell's spectrum is transformed into a spatial resonance resembling an indoor metallic enclosure, and therefore moves the listener away from the 'outdoor' implication found in the materials towards the beginning of the example.

Granulation processes can be used for more dynamic and continuous transformations from object to spatial resonances and from object to spatial occupation. Example 20 begins with a single vocal articulation. The sound begins at a clear spatial location in the listener's space. What follows is a granulation process where continuously changing parameters of grain size, grain overlap, gain, source scan speed and statistical spatial distribution transform the sound from a point source sound-object to a sound mass, alluding to a large space through the occupation of the granulated texture. In example 21, the same transformation is applied with the addition of a random distance variable. In example 22, the spatial occupation implication is transformed into the character of a spatial resonance.

Distraction

An important perceptual aspect of the object to resonance spatial transformation cannot be forgotten: in example 19, if the ear were actively attentive to the 'bell' throughout the transformation, the sound identity would have remained in the *mind* as the 'bell' object. The ear needs to be distracted from the sound-object so that the object identity is more easily forgotten. In the composition (Barrett 2000) this distraction process is taken a stage further with the addition of foreground information. An extract can be heard in example 23.

Perceptual sensitivity

Our sensitivity to change is different for various sound parameters. In general our sensitivity to changes in pitch and duration is good, while the relative judgement of spatial depth and texture is less good (McAdams 1989: 182, provides a detailed discussion). This means that if the pitch reference (or lack of reference) remains stable, the ear is more likely to accept the object–space transformation. In the above example, the 'bell' spectrum is clearly pitched, and this parameter remains constant throughout the transformation.

4. PLAYBACK, SOUND REPRODUCTION AND PERFORMANCE

Consideration of the composed space cannot end in the studio. The space in which the music is heard and the way it is performed have important consequences for the spatial aspects in the music. A consideration of the position of each member of the audience in relation to the spatial information is also important. In sound diffusion, the performer normally attempts to provide a reasonable spatial picture to the complete audience, accepting that each individual will receive a different view. In the 3D sound field the audience's position may change. In ambisonics sound field reproduction, across the area where the sound field is sufficiently reproduced, each member of the audience hears a similar sound picture regardless of where they sit. In other words, this is a one-to-many mapping, as explained by Malham (2001).

The studio is a controlled composition laboratory where the composer is situated in the ideal position. Even when working in the stereo field, under studio conditions the composer/listener can be drawn into a deep and clear spatial picture. This listening situation can be fragile outside the studio due to the acoustics of the listening space, the location of the listener and the quality of the loudspeakers.

Out of the studio there are a number of choices in the sound projection method. In the private space the listeners are responsible for their environment, and there are many choices available. These range from headphone listening, hi-fi stereo reproduction (potentially as good as the studio environment), to multi-channel reproduction. The choice is limited only by the source provided by the composer.

4.1. Projection outside the studio: in public spaces

The listeners' space

The acoustics of the listeners' space influence all spatial information in the music. If the music lacks aspects of spatial illusion apart from a pair-wise linear panning of the sound, the listeners' room is the music's sole enclosure. Any other spatial implication in the music will be added to by the listeners' room. The size, shape and absorption characteristics of the space are important considerations that influence most strongly the intended intimacy between sound and listener. No matter how skilled the performer, nor how accurate the 3D sound field, a loss of intimacy resulting from listening space reverberation and reflections cannot be corrected. The traditional avoidance of acoustically realistic reverberation effects in acousmatic music intended for concert performance is strongly linked to this problem. Avoiding reverberation effects avoids superimposing the spatial

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illusion and the acoustics of the listeners' space. However, acoustics can be used advantageously in performance to smooth dynamic spatial diffusion, while in the ambisonics sound field it interferes with the clarity of the spatial reproduction.

Stereo diffusion, multi-channel techniques and spatialisation methods

When the performance space is enlarged, it is necessary to increase the number of loudspeakers to project the music to the audience (regardless of the audience-to-music mapping). In such situations the composer (and performer) have a choice: either split the stereo source over many loudspeakers and manipulate phantom images and point sources (sound diffusion), or use a multi-channel source. In most cases a stereo source is all that is available. The reasons for, and the history and design of sound diffusion systems are well documented by Harrison (1998). With experienced performance and *interpretation* of the space in the music, an exciting result can be achieved. However, the performer is often unable to recreate the composed space in the concert hall. It can be difficult to give the illusion of separate sound images from the stereo field, and spatial information generally loses definition.

The quantity and placement of loudspeakers

An alternative to splitting the stereo source is to produce the final work in a multi-channel format. Regardless of the spatialisation method, in considering the number of channels and their position in the space, two alternatives are available. Both suffer from bad tolerances in speaker locations (less of a problem in sound diffusion as the performer can account for variations in performance space acoustics, loudspeaker colouration and speaker position). One choice is to work with a practical number of channels for storage and playback; traditionally eight channels, stemming from eight-channel playback media such as Alesis A-DAT, Tascam DA-88 and computer sound cards. Alternatively, the composer can follow commercial demands for consumer multi-channel systems in number of channels and speaker placements. Surround sound systems such as 5.1 and 7.1 are available, the former being more common.

The spatialisation method

In addition to deciding on the multi-channel format, one needs to decide on the composed spatialisation technique. Although sound diffusion of the stereo image is a spatialisation technique, it can rarely be accurately considered in the compositional process. At the composing stage, the choices are twofold: (i) Combine panned mono sounds with multiple stereo phantom images as stable or moving subjects, including manipulation of the spatial illusion and spatial allusion; (ii) Encode 3D spatial information, which will include illusion and allusion information, and then decode the composition over the chosen loudspeaker array. Commercial 5.1 and 7.1 surround 'sound-tracks' normally use the former method, and even though the process includes an encoding stage, this stage is designed to reduce the quantity of data rather than improve the spatial information presented to the listener. When projecting conventional 5.1 recorded material in a concert space, the results are often less interesting than performed sound diffusion or 3D sound field recreation. This is simply because the use of five loudspeakers in a public space does not offer a large variety of spatial pictures. The spatial picture is confined to static sound fields of low spatial information, articulated by a second layer of moving or stationary point sources or phantom images. In larger spaces the distance between the speakers will lead to a loss of spatial image for many audience positions. Encoded 3D sound fields partly overcome these problems, but use of five loudspeakers still provides poor spatial coverage.

5. CONCLUSION

Aspects of the spatial illusion in the stereo field, sound collage, or the motion of 'dry' sound in the listeners' space, are those traditionally used by composers. However, by including aspects of allusion and the advantages of the 3D synthesised sound field, the composer's spatial options begin to increase. Musical examples from the repertoire where spatial allusions are important to the music can be found. However, this paper presents a closer look at how these devices can be used as a primary and not subsidiary part of the sound and compositional development. In addition, the author's work with ambisonics has hopefully added a new perspective: allowing previously conceptual ideas to be realised in practice.

Spatial information can be direct and exact as in the spatial illusion, or vague and open to interpretation similar to other aspects of sound identity. Connections to the real world and to our physical space are significant for spatial development, possibly more so than intrinsic attributes of the sound, and provide a rich field for discussion and interpretation. Contrary to self-referential music, spatial elements find strength in their connection outside the work.

Most compositional spatial development techniques are dependent on how the sound is transmitted to the listener. Many of the observations and investigations presented in this paper became apparent through an experience of different performance situations, different spatialisation methods, and experimentation both in and out of the studio.

SOUND EXAMPLES

Sound examples are in stereo format where possible. The following examples are available only in four-channel format on the following web page:

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http://www.notam02.no/~natashab/ambiex.html
Examples 12a, 12b,13; Examples 14a, 14b, 14c; Examples 15a, 14b, 15c.
Examples 20, 21, 22 are available in stereo and four-channel formats.
Playback instructions are found on the web page.

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