Diffusing Diffusion: A History of the Technological Advances in Spatial Performance

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ABSTRACT

This paper assesses current trends in diffusion performance practice. It aims to identify the most important stages of development in diffusion and its related fields, and how historical events have continued to influence modern diffusion practice. The main focus is on advancements in spatialisation techniques and the way they helped catalyze new movements in diffusion. A split in two schools of thought within diffusion is recognized and each of these is discussed. The paper also looks at the way both stems of diffusion have more recently, embraced the design of custom interfaces focusing on the ways they aim to increase spatial expressivity in performance. Three main areas of diffusion interface design are discussed in depth and examples from each category are given.

1. INTRODUCTION

The spatial nature of music has always been present, but has often been placed without as much importance as other aspects of music. Sound diffusion is one field that has placed a greater importance on using space in the concert hall as an expressive parameter of performance. Diffusion systems have undergone several periods of development over time, but always with a desire to heighten the electro–acoustic musicians engagement with space in their pieces. This development has, at various times, been focused around all aspects of diffusion, from the algorithms driving the spatial field, to the design and layout of speaker orchestras, and the varying interfaces used by performers.

This paper provides an overview of significant developments throughout diffusions history and assesses their impact and influence on current trends in the performance practice. After this introduction, it presents a discussion of diffusions early history. The third section looks at advancements in spatialisation algorithms and their affect on the field. There is a focus on expanding the presence

of the speaker orchestra, and effects and techniques implemented for new systems. The result of these advances has caused the field to branch off into two diverging paths, the fourth section discusses the similarities and differences between these two paths and how they have each undergone their own advances. Finally, the paper gives an account of one of the most prominent current trends in diffusion practice, that of developing new performance interfaces. A wide range of new interfaces and systems are discussed with a focus on the ways they are attempting to increase expressivity and gestural interactions in diffusion performance.

2. EARLY HISTORY

In 1951 Schaefer and Henry presented potentiometer de space. They were able to perform a piece of pre-composed electroacoustic music by dynamically spatializing the sounds through a tetrahedral speaker array. They used a custom built interface to control the gain of each speaker and thus the spatial field [1]. From this point on French schools of acoustmatic music placed a strong emphasis on expressive spatialisation in both studio and performance techniques.

Spatialisation concerts became a common occurrence in acoustmatic concerts across Europe and the United Kingdom. Many prominent institutions invested in large-scale speaker orchestras throughout the 1970s and 1980s. Some of the most notable examples include the GRM Acousmonium [2], the Institut de Musique Electroacoustique de Bourges (IMEB)'s Gmebaphone [3], and the University of Birmingham's BEAST [4]. The early orchestras consisted of a relatively small number of speakers, for example in 1973 The Gmebaphone featured around 20 speakers, mostly made up of pairs of speakers each pair with unique characteristics, therefore coloring the sounds played through them in an individual way. It was this differing coloration and the physical spatial positioning of speakers both on stage and throughout the concert hall that the diffusion artist used to manipulate and interpret the space in their piece.

Speaker orchestras were often capable of travelling and therefore were set up in many different concert spaces. The ability to adapt to a new space was an integral part of their success given that at this point in time the diffusion artist's main aesthetic was based around a live interpretation of their piece in the concert space [5].

3. ALGORITHM ADVANCEMENT

In all of the systems so far discussed the performers aesthetic decisions are based around expressively manipulating the way sound is dispersed through a room. The routing of the particular system greatly influenced the potential for creating dynamic trajectories in space. The most common routing set up for early systems was to have pairs of speakers separated left/right but equally spaced throughout the room. This is an intuitive set up as the vast majority of pieces played on the speaker orchestras are composed in stereo. Therefore they already hold the left/right spread data intrinsically.

The increasing sophistication of spatial rendering algorithms has greatly influenced diffusion performance. With the increasing accuracy of perceived localization in stereo sound, some composers began to experience and desire the creation of phantom source positions in their compositions. This increase began with research into the psycho-acoustics of human hearing that lead to more accurate pan-pot laws for stereo panning [6]. Further increases came in the 1990s with developments in Vector Base Amplitude Panning [7], Wave Field Synthesis and Higher Order Ambisonics. Whilst a thorough explanation of advanced spatialisation algorithms is beyond the scope of this paper, it is important to note that all of these techniques rely heavily on very specific, equidistant speaker arrays. Both VBAP and ambisonics are only accurate in a pantophonic ring, with a minimum of eight speakers. Phantom source creation gains accuracy and perceptibility as the number of speakers used increases. Thus to use these techniques in diffusion concerts the configuration of the concert hall would need to be optimized.

Technological advancements meant composers could now think about spatialisation in their pieces in a very different way, and engage in a new wave of spatial aesthetics. Tools for control and rendering of these techniques found their way into the Digital Audio Workstations (DAW's) that composers use in the studio. The most common forms of spatialisation tools allowed the composer to drag a virtual representation of a sounding object and place it within a depiction of the speaker array. This technique proved intuitive for new users and clearly afforded composers with the expressive capabilities they desired, as this user interface is still highly prominent in DAW's GUI (graphical user interface) design today.

In the studio composers have as much time as they need to place sounds exactly where they want and trace out specific trajectories with the mouse on the screen. However in performance, all motions need to be achievable in real time. As spatialisation algorithms became more sophisticated composers were able to think about where they wanted to place sounds discretely within the space rather than just the way they were dispersed. In light of this, from the late 1990s onwards we are able to recognize a significant split in the paradigm of diffusion practice. The results of which will be discussed in the following section.

4. RECENT TRENDS IN DIFFUSION

In the 90s we started to see a change in the way some composers where approaching spatialisation in their pieces both in the studio and in performance. Previously, in diffusion concerts the composers intent was to use the speakers acoustic qualities and placement within the concert hall to color their compositions [5], [8]. The aesthetical engagement was with the overall perception of the piece in the environment, rather than the placing of a specific sounding object in a discrete location (90 degrees left of the sweet spot for example). In this approach the audience perception to the composers intention is very much a function of their position within the space. As these concerts tended to take place in a similar configuration of that shown in Figure 1, that is, the performer positioned in the sweet spot and the audience seated generally behind the performer with little to no view of the performer. This gives the audience a very different perspective of the spatial field than that of the composer.
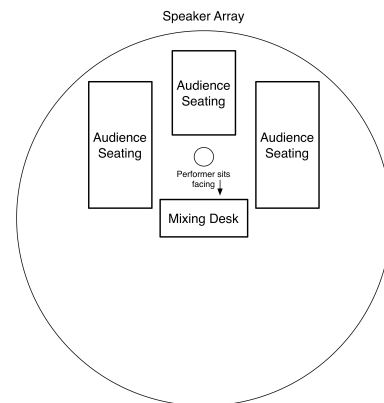

Figure 1. Traditional Diffusion Concert Setting

The authors have identified a significant divergence of two separate branches in diffusion performance. The first, room-based diffusion, holds the ideals of the spatial interpretation of the piece but has undergone significant advancement in technologies and techniques used. The second, phantom source positioning diffusion, embraces advanced spatialisation algorithms with the goal of creating dynamic spatial fields. This second branch is currently undergoing rapid development with many research institutes across the globe devoting time and resources into the control of source positions in performance, and gestural interactions between the performer and the space.

There are common trends in development between the two branches, and many systems make attempts to blend them. For example, both branches of diffusion have shown a strong desire to increase the complexity of potential spatial trajectories. This is often implemented with an emphasis on behavioral functions exhibited by particle systems, such is the case in [9], [10], amongst others. Both branches have also exhibited a strong interest in the development of 3D and spherical sound fields.

There are also many areas of development that differ between the two branches. Source positioning diffusion

has begun to place a greater importance on the performance interface used in concerts, and focus development on advancing interfaces for intuitive spatial control. This affords an ability to make complex trajectories be gesturally and intuitively performed in real time. Whereas in room based diffusion, the development has being focused more on software and PC based GUI designs rather than physical interfaces. Each of these branches, and significant examples from them, will be discussed in the following subsections.

4.1 Room Based Diffusion

The original ideas of coloration and live interpretation developed with travelling speaker orchestras had a lasting impression on the spatial performance field. This branch of diffusion is still the most common. Both the BEAST and Gmebaphone systems are still in use and continuing to evolve today. In the late 1990s the later had a name change to the Cybernephone to reflect the ability for netwroked performance as will be discussed shortly. There have being a number of areas within the speaker orchestras that have experienced much development over time.

The BEAST system now regularly features over 100 speakers that can be configured in many different ways. As the power of the modern PC advanced, systems were capable of more complex audio processing. One of the most significant advancements to speaker orchestras has being the inclusion of advanced software tools for the programming of autonomous spatial trajectories, and complex spatial distribution patterns. Birmingham has released BEASTmulch the software that now drives the BEAST concert system, and alongside it BEAST-mulchLib, a super collider class library that includes many tools for diffusion performance, including interfacing with MIDI controllers, implementing spatialisation algorithms and automating trajectories. For further details about this system please refer to [11].

The Gmebaphone system has always placed great emphasis on the coloration provided by varying the types of speakers used and ensuring the highest possible audio quality right through the signal chain. In 1997 with the sixth iteration of the Gmebaphone, the system went digital and was renamed the Cybernephone. With a digital system came a new range of possibilities for networking, this quickly became a major emphasis and asset to the system. The Cybernephone is capable of sophisticated networked diffusion; composers can also pre-record all their spatial trajectories and have them played back for the concert. Whilst arguably significantly reducing the performative element of diffusion concerts, this does greatly increase the complexity of potential trajectories, thus fulfilling a major goal in both branches of diffusion.

Complementing developments taking place through these flag ship systems, a new wave of diffusion systems, with less emphasis on the ability to travel has arisen. Some systems such as Belfast's SARC, exhibit an ability to easily adjust speaker configurations within the space, and include speakers under the floor. The University of Sheffield's M2 [12] and later ReSound [13] also aim to increase expressivity in diffusion performance. M2's matrix routing system is highly configurable so on the fly routing changes can be incorporated within a piece, and the ReSound system adds to that an ability to include some autonomous motions that can be triggered and affected in real time. These systems have encouraged a new level of modularity and usability making the art of diffusion performance accessible to a wider range of composers as well as creating an engaging and fully immersive experience for the audience member.

Throughout these systems there is also a focus on the reproduction of holophonic sound fields within the wider sonic environment. It is common place for a larger speaker orchestra to be divided into sub groups and have, for example, a middle eight speakers implement a VBAP algorithm. There is also the capability to designate a particular spatial motion to a group of speakers such as BEAST's Spatial Swarm Granulation [11] or ReSounds Mexican Wave [13]. While these more realistic spatial renditions are not necessarily as prominent in this branch of diffusion as they are in the next, they are present, and room-based diffusion has still been greatly affected by algorithmic advancement.

4.2 Phantom Source Positioning

Running parallel with developments in the sophistication of the speaker orchestra, a trend to increase the accuracy of phantom source positioning in spatial fields has risen. Concerts from this branch of diffusion have placed less emphasis on increasing the amount of speakers they are able to drive, and more on the creation of a holophonic sound field, made possible by the advances in spatial algorithm rendering as discussed in section 3.

One of the major advantages of this approach is that fully immersive sound fields can be created with as little as eight loudspeakers and one standard audio interface, thus significantly reducing the cost of providing such a system. With much shorter, though still considerable, set up times and often a performance environment closer to that of a studio, composers are often afforded more rehearsal time in the space.

The GSMAX software [14] aims to encourage dynamic sound field creation by affording the performer an ability to trigger complex, pre-defined spatial trajectories and dynamically set them in motion. In traditional diffusion performance practice the artist actively engages with the system by directly adjusting the gain of individual speakers, or pairs or groups of speakers, however in source position diffusion the performer is manipulating the perceived position of a source. The system makes the appropriate calculations to control the speaker gain, and create the phantom source.

Another approach is the large-scale multi-media dome environments. One of the early examples of this is Stockhausens Osaka World Fair of 1970. The University of California, Santa Barbara's AlloSphere [15] transcends a traditional diffusion environment. It is used for both performance and interactive installation and includes 3D visuals as well as spherical sound.

The phenomenon of the 'sweet spot' plays an interesting role in this branch of diffusion. Traditionally in diffusion concerts there is still a strong notion of a stage,

though no performer is present on it. The mixing desk (and therefore performer) is set in the middle of the space and the audience set behind and sometimes in front of the performer (refer to Figure 1). Very few audience members are situated within what would be considered close enough to the sweet spot to get an accurate spatial image. The physical implications of seating an audience mean this will always be the case in a concert setting, however the importance placed on the sweet spot is diminishing. Concerts at the author's own institution take place with an 8-channel speaker array driven by VBAP algorithms. The concert setting attempts to try to place all audience members within the speaker array, but place the performer in the sweet spot as to link physical performance gestures more transparently with perceived trajectories. Again, no audience member experiences the same sound field perception as the performer does, the emphasis is placed more on the dynamic movements of sound, which are perceived independently of the sweet spot, rather than the discrete localization of an exact location by all audience members.

Speaker Array

Audience Seating

Touch Table

Performer stands facing
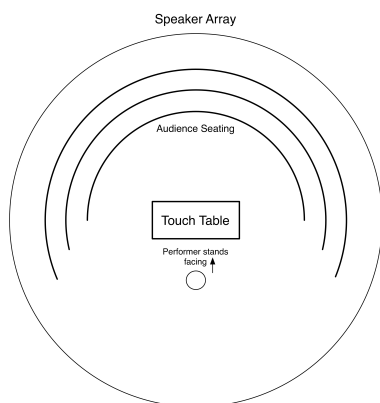
Figure 2. A new arrangement for concert settings

With performers now interacting directly with source positions rather than speaker gains, many researchers in the field have begun to question the validity of the mixing desk and indeed, the vertical potentiometer, as a desirable user interface. The ergonomics of the mixing desk, significantly limit the types of trajectories able to be performed. This problem is well recognized within the field [14], [16], [17]. This has given rise to a new sub-field of diffusion practice that is currently in a phase of rapid development: the design of custom performance interfaces for diffusion practice. This new sub-field has been largely driven and focused by source positioning diffusion, however it does span both branches of diffusion and will be discussed in depth in the subsequent section.

5. PERFORMANCE INTERFACE DESIGN

The authors have observed that the majority of new interfaces being used for diffusion performance can be arranged into three categories; those using existing tools, mostly from the gaming industry, multi-touch interfaces for both tablet and table-top surfaces and entirely new interfaces inspired by the NIME community. The advances discussed in Section 4 have worked to encourage new aesthetics in diffusion and afford the performer

heightened control of the spatial positions in the sound field. The subsequent sections will look in depth at each of these categories and introduce some notable examples highlighting their strengths and weaknesses.

5.1 Hacking Existing Tools

Interestingly enough the mixing desk is by far the most notable user interface from the existing tools category. Originally designed for the recording industry, this interface was built to take multiple lines of audio input simultaneously and mix them down to much fewer (usually stereo) lines of output. Many standard mixing desks have at least 8 direct outputs, therefore the interface does work surprising well for the purpose of sound diffusion, however many performers over time have found the interface ergonomics to be quiet limiting to the potential sonic trajectories. As there are no specific standardized fader assignment configurations, performers need to quickly adjust to whatever set up is most commonly used for that concert space, which may or may not be the set up they have rehearsed on or the set up they prefer. When every performers individual needs are taken into consideration the concert ends up with very complex configurations and lengthy change over times between pieces.

The BEAST system uses a customized mixing desk that has being optimized for large–scale diffusion. The M2 and ReSound systems take it one step further with a fully custom built fader interface that can be rotated 90 degrees to give a more intuitive relationship to left/right motion. Resound can be used with any MIDI controller, and the faders (or other control sensors) can be dynamically mapped to speaker groups or behaviors properties on the fly. Whilst these advances certainly increase expressive control and potential sonic trajectories, the fader based user interface leaves us with many of the same problematic couplings caused by the mixing desk that these systems aim to reject.

Research into gestural controllers for the gaming industry has seen artists from many fields appropriate these tools for their artistic practice. Joysticks [18], Gametraks [19] and Wiimotes [20] have been common controllers in popular electronic performance, and have been used for spatialisation. More recently the Microsoft Kinect, has become very popular for gesture tracking in performance.

The Centur[1], from University of Montreal is being used in conjunction with artist driven customized software as a diffusion interface for control of a 3-dimensional speaker dome (similar to the Allosphere discussed in section 4.2). The Kinect recognizes specific performance gestures to 'pick up' and move sounds through the space, with a separate gesture to 'put down' or leave sounds once they are moved. In theory this system is very intuitive allowing a direct mapping of physical movement to sonic output. The performer is limited (as in many systems) to moving only two sounds at a time, as they only have two hands with which to create gestures. However, the systems does allow for a highly

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[1]http://www.behance.net/gallery/Centor-Gestural-interface-for-live-sound-diffusion/8926479

expressive range of sonic trajectories to be performed. Although the implementation of gestural spatial movement is very intuitive, systems such as these can take long calibration times and have many quirks to learn, taking up valuable rehearsal time. Other gesture tracking systems will be discussed in section 5.3.

5.2 Multi-Touch

The introduction of the Reactable [21] in 2005 saw the wider electronic music industry embrace the use of multi-touch surfaces as a performance interface. With the majority of early applications for such devices focusing on synthesis models, it quickly became apparent that such interfaces have use not only in performance but also for collaborative installation and as a studio tool as well. A few research teams [22], [23], have explored development of multi-touch studio mixing tools. These tools have included spatial rendering, however they have largely been limited to stereo or quadraphonic speaker systems.

The SoundScape Renderer first devised as a spatial rendering system for collaborative installation and studio use, started as an application for large-scale multi-touch table [24]. A later version was ported for Android and is now a free downloadable application for Android based systems [25]. The system is capable of higher-order ambisonic, binaural or VBAP rendering. The SoundScape Renderer employs an object-based approach where the user interacts with graphical representations of the each audio file rather than focusing on control of speaker gains, as is the case with traditional mixing desk diffusion systems. This is a common trend amongst new interface driven diffusion systems

tactile.space [26] was built by the first author to run on table-top surface, The Bricktable [27]. Many music performance applications had being built for The Bricktable previously [28], but tactile.space was the first specifically designed for diffusion performance. The application allows the user to input the number of speakers and audio files desired as well as other customizable user settings, before compiling. The user is then presented with a GUI where they can simply drag visual representations of each of their sound files into their desired location within the spatial field and a real time spatialisation will occur. The interface proved successful in many aspects with an easily learnable and intuitive user interface. tactile.space not only made it easy for artists to perform complex spatial trajectories, but also introduced control of spatial spread. By placing a second finger inside an audio object the user was able to spread the object into an arc shape to widen the perceived sound source. The arc's position and distance could then be adjusted by moving small circles drawn in the arcs centre and the width of the spread could be adjusted by moving either of the circles at the arcs edge. The arc can be spread into a full 360-degree circle to completely immerse the audience. tactile.space was evaluated by composer-performers who worked with the interface in 2012, the results of this evaluation can be found in [29].

The latest research from the author includes a version of tactile.space, named tactile.motion routed to iPad . The GUI itself follows the tactile.space visual aesthetic. It has many of the same features and modularity. tactile.motion also introduces new functionality to encourage the creation of more dynamic spatial fields. Specific intuitive gestures are recognized by the system and used to trigger autonomous spatial behaviors. For example, if the user moves an audio object in a circular motion the system is able to recognize the intention to draw a circle and will continue the spinning motion at the velocity drawn by the user. The short set up time stability and intuitive GUI all afford the user more time to focus on the spatial aesthetics and performance.

5.3 Entirely New Interfaces

Inspired by the New Interfaces for Musical Expression community a new wave of custom-built controllers have emerged as interfaces for diffusion performance. Many of these systems are similar to the Kinect based gesture tracking systems, but include artist built controllers attached to the performers hand that can be tracked. There are also examples of entirely new physical interfaces built to compensate for the ergonomic weaknesses of the mixing desk as a diffusion interface.

One of the earliest examples of a gesture tracking based system is SARC's Hand-Held Light Emitting Pen Controllers [16]. By placing an LED on the pen its position can be tracked by a computers camera. The performer holds one pen in each hand and the position is directly mapped to the spatial position of each half of a stereo signal. This system affords highly intuitive control of spatial trajectories; however it limits the performer to control of only two stems at a time. Each pen has two LED's so the system is able to recognize a twist of the wrist, which is mapped to 'source spread'. The system encourages intuitive relationships between gesture and sonic trajectory, and affords the performer a wide range of trajectories and therefore expressive control of space. However, like all vision tracking systems, the performer is limited by their own reach and controlling only two stems simultaneously, as well as by tracking capabilities, eg sensitivity to stage lighting and proximity and line of the performer to the camera.

The dataglove [30] is a diffusion system where the performer wears a custom glove that sends spatial position information able to be unpacked in either Max/MSP or PD. The A.R.T. system used makes to resolve some of the limitations of tracking systems that rely on being within the line of site of one or two cameras, by using up to six infra-red cameras. The user has reflective spheres placed on their hands, and each sphere only needs to be within the view of at least two cameras to have its position tracked.

An example of an entirely new interface designed specifically for sound diffusion is the authors own Chronus [32]. Chronus features a rotary encoder based design for spatial positioning in a pantophonic field. The rotary encoder is similar to a standard knob based potentiometer, however it can be continually rotated past the point of 360 degrees. This allows the position to be directly mapped in space without limiting any spin-based trajectories to one circle motion as standard knobs do. The second version of Chronus, Chronus2.0 [33], also includes a

slide potentiometer placed on top of the spinning disc so the performer can control both angle and radius positions within a pantophonic speaker array. The positions are read by an Arduino microcontroller, which can in turn send the data via serial or OSC protocols to be unpacked in custom built Max or Processing patches. Whilst thus far both versions of Chronus have only being used with the authors custom built software, given that the interfaces itself just sends standard polar coordinates it could easily be used in conjunction with the VBAP object in Max, or any other spatialisation system. This modularity was one of the main design features of the Chronus series; it should be easy for any diffusion artist to adapt to the new interface without limiting or affecting their current spatialisation system.

Figure 3. Timeline of significant Diffusion Systems

6. CONCLUSIONS

Diffusion systems and performances have come a long way since their conception in the 1940s. Whilst the concert setting, the speaker orchestra and the performance interface have all undergone significant change, diffusion has remained a primary form for performance of multi-channel acoustmatic works. Influenced by the advancement of spatialisation algorithms through the 80s and 90s,

the most prominent current trend is the design of custom user interfaces for performance practice.

New user interfaces have emerged across the field and taken many forms, however there are common design goals in mind. These new interfaces have a focus on transparency in gestural relationships to sonic trajectories, and the increasing of performance spatial motions. New software has being developed in order to make the most of these new interfaces, with some systems following the direction of giving the system some autonomy to increase the potential of complex trajectories.

Amongst all the turns the paradigm of diffusion performance has taken the original goals of diffusion are still the driving force of all development; to increase the composers aesthetic engagement with space.

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