Exploring 'Synaespatia' within a Networked Musico-Spatial Virtual Environment

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This paper addresses the conference theme of futuristic co-creation through inter-disciplinary research that brings together the fields of spatial design, music and sound and spatialisation in virtual reality (VR). We describe a 'Networked Musico-Spatial Virtual Environment' (NMSVE) that spatialises, in real time VR, frequency distribution and wave forms of live and recorded sound, provides a form of real-time 3D spatial notation of musical instruments (digital drum kit, keyboards) and sends and receives these spatialisations to two or more participants in different continents across the network. Through the NMSVE, new forms of 'synaespatia' can be enabled as the experience of sound and music through cross-domain spatialisation across a range of networked performance modalities. Whilst the technologies were developed primarily to advance musico-spatial performance, they offer significant potential to enable new understandings of sound and music for the hearing impaired and as a research tool for architectural acoustics.

Keywords: *Sound Spatialisation, VR, Musico-Spatial, Networked Performance, Acoustics*

INTRODUCTION

This paper follows on from previous collaborative research that operates at the intersection of music, spatial design and visualization. We use the term 'musico-spatial' to describe the creative practice domain that intersects the musical and the spatial. We engage in the technologies of VR to enhance this creative practice. The team consists of musicians, architects and visualization experts and together we seek to explore the synergies of cross-domain, inter-disciplinary practice.

The research, commencing in 2016, has been interrupted by the Coronavirus pandemic. Whilst the research team has been unable to physically to travel between Australia and Europe, this has provided an opportunity to enhance the capabilities and potential of the project through the use of networks to send and receive musical and spatial data. This, in turn, has allowed us to address the conference theme of 'Co-creating the future: inclusion in and through design'- from a non-traditional perspective that utilizes live performance as a means of exploring the musico-spatial domain.

STATIC AND DYNAMIC MUSICO-SPATIAL CROSS-DOMAIN REPRESENTATION

As part of a larger creative practice PhD, the first author developed the concept of Cross-domain Representation (XDR), using the digital drum kit as the basis for musico-spatial translations. A representative selection of improvised digital drum solos were recorded MIDI, exported as Microsoft Excel files, then imported into Rhino3D Grasshopper (GH). Through a series of GH definitions, a wide array of flexibly modelled spatial outputs are enabled.

The foundation of this work is the spatial translation and transformation of three musical parameters relating to drumming: timing (the placement of notes within time); note selection (which drum notes are played within a performance) and dynamics (how hard or soft the performer plays). The drummer, during an improvisation, makes designerly decisions on *what* drums are played, *when*, and with what *dynamics;* as 'the designerly placement of dynamic note events in time'.

Figure 1, below, illustrates nine drum solos translated and exported into GH. 16 drum notes radiate clockwise, with time projecting from the centre outwards and the rippled surface produced from placing a loft over the dynamics data points. Using this definition, each drum solo is given an unique spatial form. Referencing the 'liquid architectures' of Novak (1991), we call these static representations 'liquid polyrhythm'.

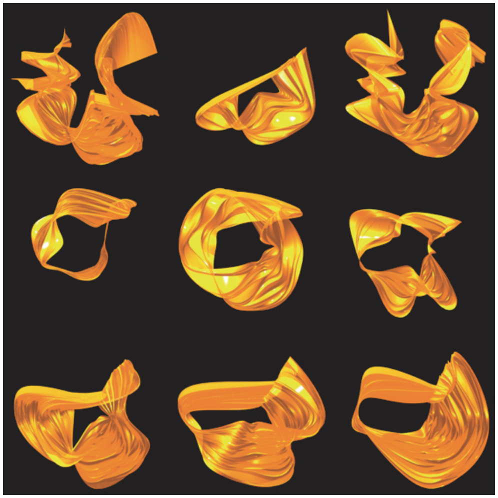


Figure 1
GH spatialisation of nine drum solos

The next stage of development (reported in Ham et. al., 2019) was the development of the dynamic spatialisation of digital drumming through the Virtual Drumming Environment (VDE). The VDE is based on a purpose-driven application within the Covise and OpenCover Virtual Reality (VR) visualisation suite developed at the University of Stuttgart High Performance Computing Centre (HLRS). The VR spatialisation is generated in real time by the translation of MIDI signals (time, note events and note velocity from a Roland TD20 digital drum kit into spatial parameters. VR output is experienced through the interface of a HTC Vive head-mounted display (HMD), inside a CAVE and as screen-based projections.

The VDE was designed to allow the drummer to experience, in real time and in first person, the dynamic spatialisation from the point of view from the seated position on the drum kit. The VDE provided a platform for live musico-spatial performance in VR. This stage of the research culminated in a performance for the first author's architecture and design PhD examination in 2018. In this performance, the author, demonstrated the performance between and across domains: from the musical (playing the drum kit as a musical instrument), to the spatial (playing the drum kit as a spatial form generator) to the musico-spatial (playing the drum kit both musically and spatially at the same time) (see https://vimeo.com/303176359). This final performance modality extended the capacities of the digital drum kit both as a design research tool and as a means of exploring new means of musical and architectural (spatial) expression.

Figure 2: Musico-spatial performance in the VDE.

Whilst this is of interest, both XDR and the VDE are limited to the drum kit and, critically, to the use of MIDI as the translator between the musical and the spatial. In order to explore further, we sought to introduce more digital instruments and to examine ways in which sound could be spatialised.

A NETWORKED MUSICO-SPATIAL VIRTUAL ENVIRONMENT (NMSVE)

The NMSVE is a networked environment to support the spatialisation of sound and music in virtual reality that operates within the OpenCOVER VR rendering system within the COVISE software framework. COVISE is a parallel distributed rendering system which supports rendering for high end VR environments such as CAVEs but also scales down to the HTC-Vive. Utilising the code and configuration settings developed for the VDE, the NMSVE extends beyond the focus on drumming to include the input of sound. This can be sourced from the 'room sound' from a microphone, musical instrument direct input or sound from a Zoom, Webex or similar teleconferencing platform.

In addition, the NMSVE adds a capacity for configurable instrument input for any MIDI-enabled instrument (eg keyboards, digital theremin). Drawing from the field of 3D musical notation (see Hope et. al. 2015), we offer an advancement of musical notation that operates in VR from a first-person perspective that represents the dynamics, interconnections between notes in a phrase and placement of notes within a scale. To achieve this, a configuration file is set up that assigns a note position and colour for each of the 12 notes in a musical scale. These are repeated for each octave.

In the VDE, only digital drum kits have been supported. Drum pads typically only provide one Midi Event, a "Note On" event with a single parameter "velocity" depending on how hard you hit the drum pad. These events have been visualized as spheres with varying radius depending on Velocity. The spheres are emitted from a specific 3D location and travel through space on trajectories defined by a set of parameters. For the NMSVE we also implemented "Note-Off" events. Keyboards for instance generate both, a "Note-On" when pressing a key and a "Note-Off" event when releasing the key. A Note-On-Off pair is visualized as a bent tube where the length of the tube depends on the length of a key press. Single Midi Events can have an arbitrary shape which allows to differentiate between different instruments. Colour and texture of each event can be either modelled individually or defined by a color map depending on the pitch of the note

We have also developed a method for the real-time control of VR output of music using DJ controllers. DJ controllers allow a much more versatile method of controlling the VR output than using sliders in the OpenCOVER interface. To achieve this, the DJ controller is connected to the VR-ready laptop and each MIDI controller input is 'trained' to manipulate the speed, degree of rotation, size of notes and other aspects of the VR spatialisation.

Critically in times of Covid, the NMSVE is set up so that MIDI data can be sent and received via the network from geographically distant collaborators- in this instance, between Germany and Australia. for example, the MIDI data from a musical performance in Australia can be spatialised inside the CAVE in Germany, with output controlled by a DJ controller and vice versa.

The NMSVE setup utilises the following basic equipment (refer Figure 3):

1. The CAVE at the Stuttgart HLRS and/ or HTC Vive virtual reality gaming setup;
2. Microphone input used as the source of sound input into the NMSVE;
3. 8 channel mixing desk: this allows multiple inputs for the NMSVE including multiple musical instrument sound inputs (eg drums, keyboards and guitar), input from a digital audio workstation (not shown) and any other live input;
4. VR-ready laptop with OpenCOVER configured: this generates the VR output which can be projected into a space via HDMI cable;

5. DJ controller: this is used to control the various parameters of the VR spatialisation in real time.

Figure 3: MSVE basic equipment

Designing a Sound Spatialisation

The concept of music visualization has its origins in the Colour Organ. Wilfred's Clavilux, Hall's Musichrome and Bentham's performances of 'colour symphony' on the Light Console, Wilfred's Lumia Suite represent musical visualization interfaces that allow the 'complete integration of form and content' (Peacock 1988).

Modern musical visualization operates as static and dynamic modalities from live or previously-recorded sounds from MIDI or soundwave sources. The static representation of Shape of Song by Wattenberg (2002) 'draws musical patterns in the form of translucent arches, allowing viewers to see-literally-the shape of any composition available on the Web. The resulting images reflect the full range of musical forms, from the deep structure of Bach to the crystalline beauty of Philip Glass. The music visualizers in Mac OSX and Windows media player systems or in applications like MilkDrop[1] exemplify technologies developed purely for entertainment purposes. Dynamic music representation applications such as the Music Animation Machine[2] deploy a self-similarity grid to visualize the time structure of musical waveforms which helps comparing audio recordings for their acoustic similarity' (Chan 2007).

Music games such as Rock Band have been used to inform the learning of, and engagement in music for music students, as well as the wider community. The development of online and app-based MIDI games has enabled gamers and musicians game-like ways of interacting with their music. MIDI Jam, Riff Racer, Melody's Escape, Beat Hazard and Audio Surf provide environments where gamers can use their own music to create unique visualisations.

As architects, musicians and visualization professionals, we had an opportunity to conceive a schema for the immersive spatialisation of sound in VR. Following on from the VDE, where the spatialisation is generated around the drummer's head, we developed the concept of the 'sound tunnel- a 2400x1200mm oval tunnel within which the sound parameters and 3D musical notes are spatialised in real time from a starting position around the participants' head, projecting forward into the distance. Using the HMD or pointer inside the CAVE, the participant(s) can freely navigate this virtual environment to explore the spectacular spatialisation.

The NMSVE spatialisation comprises a top arc representing the sound wave form data points and a bottom arc generated by Fast Fourier Transform into frequency banding (from 1000-20,000 Hz). These two sound parameter spatialisations are complimentary, and work together to provide contrasting affordances (Norman, 1999) for understanding and experiencing sound through the immersivity of virtual environments.

1 (https://www.slant.co/topics/3783/viewpoints/1/~audio-music-visualizers~milkdrop-2)

2 See https://musanim.com

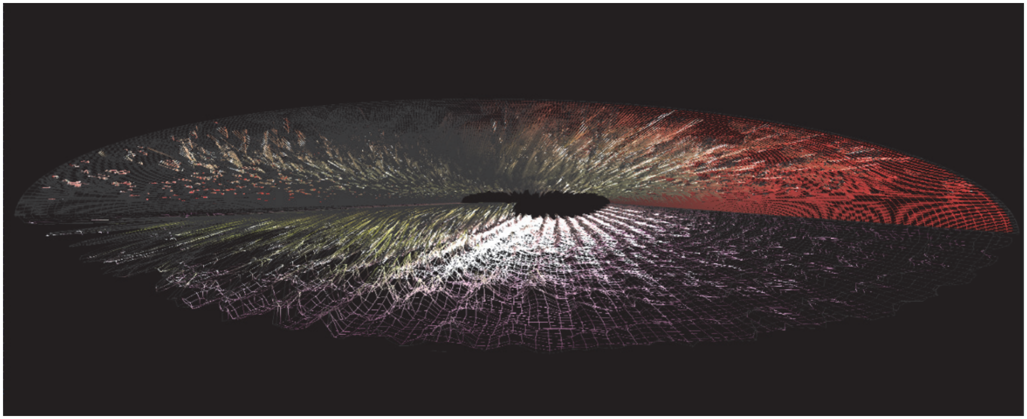
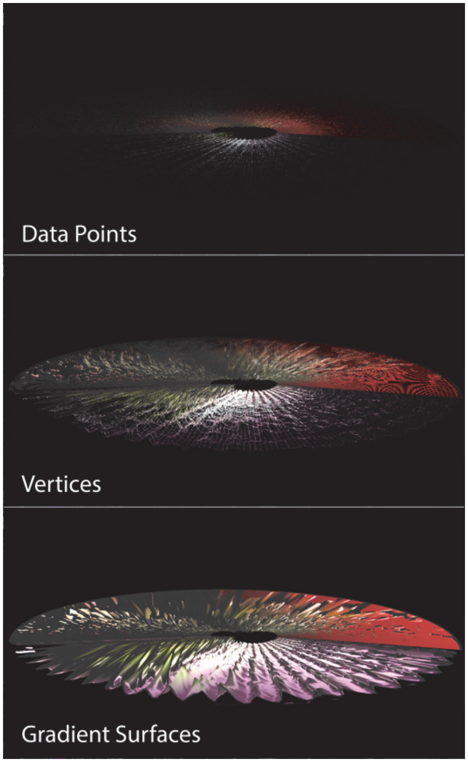


Figure 4: The 'Sound Tunnel'



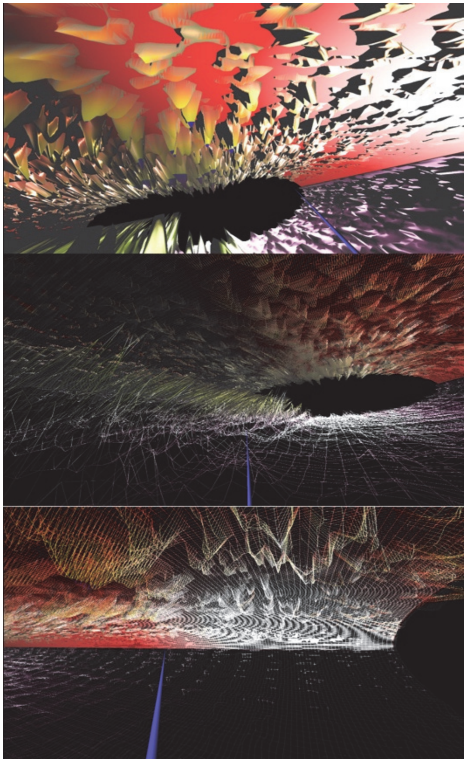


Figure 5 (left): The Sound Tunnel as data points, vertices and gradient surfaces

Figure 6 (right) : Navigating the NMSVE

EXPLORING 'SYNAESPATIA' THROUGH NETWORKED PERFORMANCE

We introduce the concept of Synaespatia. This concept borrows from the condition of synaesthesia as the involuntary stimulation of a secondary cognitive pathway (the sensation of colour) in conjunction with the stimulation of a primary cognitive pathway (hearing sound) (see https://en.wikipedia.org/wiki/Synesthesia). Through the technologies of the NMSVE, we have enabled new means of experiencing sound and music within the spatial domain.

Synaespatia is experienced through the interface of the HMD in the HTC Vive or through 3D glasses inside the CAVE. The sound (from a source such as musical instrument, recording or live input through a microphone or Zoom teleconferencing) triggers the spatialisation in real time so that direct associations can be built between the sound and the spatialisation. The Sound Tunnel can be navigated by using the hand-held pointers to walk or fly through the virtual environment. Whilst the HTC Vive limits the experience to one person at a time, the 3m x 3m 5-sided CAVE enables 4 people to individually look around the virtual environment.

In addition to the spatialisation of sound, the projection of notes from MIDI musical instruments inside the Sound Tunnel provides further synergies between the musical and the spatial domains. In addition to the basic representation of notes as spheres, these notes can be configured to project modelled objects (.obj files). The size of these notes inside the NMSVE is linked to the note velocity so that the dynamics of a performance is provided an affordance in the spatial domain. Between the experience of sound and music through the sense of hearing, the spatial perception of the sound waves, frequency and multiple types of 3D spatial notational translation and the ability of participants to freely navigate within the virtual environment and control the size, speed, rotation and other parameters of the projection; synaespatia is a wholistic construct. When two or more NMSVE's are networked (for example, between the CAVE in Germany and HTC Vive in Australia), participants experience a futuristic co-creation of sound and space where the sound generated 16,000 kilometres away can be experienced as synaespatia through the senses of hearing and sight.

Performance Modalities

The NMSVE has been trialled and tested through four performance modalities. The first modality is solo performance, where the performer plays musical instruments with the performer or an audience member experiencing the spatialisation in VR through the HMD and the output being projected to a live audience. This modality was tested at a performance at the New and Experimental Arts Lab in 2020. This modality is very difficult in that it places all the effort of both music production and VR projection on the solo performer.

The second modality is where a second person accompanies the musician to control the VR parameters, with an audience member experiencing the spatialisation using the HMD with projections to a wider audience. This modality formed the basis of the eCAADe Porto conference party in 2019. The third modality operates inside the CAVE, where the drum kit or keyboards are placed inside the CAVE and multiple audience members can experience the musico-spatial output in VR.

The most experimental modality involves the operation of two (or more) networked NMSVE's together. We have tested this at the 'Mos Eisley Cantina' breakout Zoom space for the eCAADe 2020 conference. From a home studio in Australia, the first author performed on a digital drum kit, keyboards and digital theremin, projecting sound and visuals to the eCAADe Zoom room. At the same time, the MIDI data and sound is sent to and from the CAVE at the Stuttgart HLRS. The second author (in Germany) controlled the VR parameters (in Australia) via Anydesk.

This performance, being technically advanced and highly experimental, experienced several problems: latency of sound and data between

Australia and Germany and sound cutting out due to a Zoom sound setting. Whilst latency is a common issue for real-time networked data transfer projects, this is an issue that can be factored into the musicospatial performance. A second networked performative workshop at the KLG 2020/21 Sonic Arts Symposium, resolved many of these issues.

THE RESEARCH POTENTIAL OF THE NMSVE

We see the NMSVE as a foundational technology to support new modes of interdisciplinary performance that bridges the domains of sound, music and space. The NMSVE holds significant potential in assisting the hearing impaired and deaf community being included in the experience of music. With access to musical instruments and other sound producing objects, deaf people can experience a colourful and dynamic visual-spatial representation in VR.

The NMSVE makes it possible for musicians and deaf persons to jam (co-design) together using traditional and MIDI instruments. Through synaespatia, all participants are able to enjoy meaningful interactions with music. These interactions may incite new dialogues and bring together communities and creative practitioners. Further development may involve working with the deaf community in the design of specific meaningful notation translators through the interactive making of .obj files from CAD modelling programmes that provide specific affordances to the deaf in relation to the timbral and other qualities of each instrument. This could manifest in a 'VR music translator' aside from musical performances, where the performance is translated as a musicospatial experience. Using the networking capacity of the NMSVE, these experiences and collaborations could easily be enjoyed remotely across international boundries.

Significant further research potential exists in the use of the NMSVE to enhance understandings of architectural acoustic environments. Through the use of multiple roving microphones within interior spaces or around urban environments providing input into the NMSVE, new ways of understanding acoustic environments may be enabled.

Figure 7: Testing keyboard notation inside the CAVE at the Stuttgart HLRS.

Figure 8: Solo performance with audience member interacting in VR at NEAL, 2020.

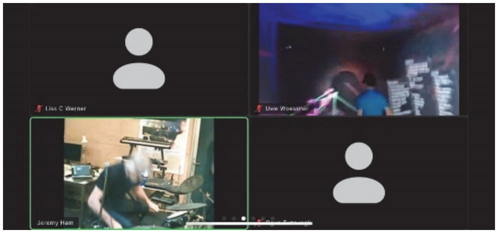


Figure 9: Zoom screenshot from eCAADe 2020 with live performance in Australia (bottom left) being projected to the CAVE in Germany (top right).

This has the potential to contribute to the many studies already undertaken in, for example, the study of sound field properties at the Sagrada Familia (Zhao et. al., 2016) and the reduction of noise and design of soundscapes in urban environments (Lacey et.al., 2019). The NMSVE, as a VR-based, parametrically flexible platform, offers a complimentary set of affordances to existing sound research technologies that could contribute to the body of knowledge of acoustics and other fields.

CONCLUSIONS

Designerly engagement in the computational tools, technologies and methods used in architectural and spatial design fields enables cross-disciplinary researchers to reveal new insights into the domains of music and sound. Although static cross-domain representation is useful for music information research, the dynamic, real-time technologies used in virtual environments enable novel new insights into the structure of sound and music.

The NMSVE, through the multiple simultaneous representations of sound parameters, musical instrument notation, ease of interface control, networking capacity and the ability of participants to direct their own free navigation in the virtual environment, forms a solid foundation for cross-domain musicospatial creative practice through performance.

Synaespatia offers a new real-time, immersive, adaptable and visually spectacular inclusive environment within which to explore sound and music. The affordances of the NMSVE and the capacity to connect geographically dispersed diverse communities have much potential to address the conference theme of co-creating the future: inclusion in and through design. We see this as the starting point for future explorations in both creative practice and research into sound.

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