Integrating Sound in Living Architecture Systems

Application of 4DSOUND in Kinetic Sculpture and Architectural Design

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Summary

We elaborate on results of our collaborations with the Living Architecture Systems Group (LASG) over the past year. Instead of additional layers of material, spatial sound interweaves meaningful fabric to sculptural form and living architecture. An architectural design now can be embedded within a sonic field (exterior), or spatial sound can form itself inside sculptural objects (interior). 4DSOUND has evolved in implementing irregular speaker setups to enhance sound projection and create applied instrumental possibilities of composing with spatial sound in the sculptural realm. We will further discuss developments regarding the integration of the 4DSOUND Engine to control other media like light, kinetics, and sensor interfaces. The paper will conclude with future research and objectives.
Projects

*Astrocyte*, DX EDIT, Toronto, Canada - fall 2017
*Amatria*, Indiana University, Bloomington, Indiana, USA - spring 2018
*Noosphere | Aegis*, Royal Ontario Museum, Toronto, Canada - summer 2018

Introduction

Sound is an essential medium in understanding space, expressing emotions, and abstracting organic and artificial phenomena like growth and electronic textures. When a physical sculpture is present within the soundscape, the spatial and physical relations between sculpture and sound requires a clearer definition. The in-depth collaboration with the LASG has challenged 4DSOUND to extend the control of sound beyond an empty space that hosts sound objects to a world where the virtual is seamlessly integrated with the actual.

The 4DSOUND paradigm considers sound by its sculptural and architectural qualities. Sounds are objects that can be sculpted with dimensions, construed sub particles, and applied properties through sound design. These objects are subsequently placed in a (virtually) infinite space where they can move following particular trajectories or according to a certain behaviour. The setup allows sound to become intimate, as close as almost touching the body, or to move like a flock of birds on a distant horizon. Inside this virtual environment, sounds are embedded with acoustic reflections to model the flexibility of sonic experience from inside a small room to a vast space. The flexibility affords the virtual environment to take on surreal forms, creating otherworldly textures and gestures that evoke imagination beyond the recognizable.

4DSOUND is an instrument, a set of tools that enables composing and performing intuitively with spatial sound in great sculptural detail. In the context of the :LASG, the challenge has been multiple. Not only do we need to create a virtual sound space - virtual sound sources that live in a 3D space which manifest through a range of speakers - that can be explored, but to integrate this sound world inside a sculpture, giving it a voice and allowing its compartments to be meaningful actors within a designed physical environment. Three R&D topics have been central in achieving these goals:

*Image 2* The large sphere of Astrocyte – the inner semi-sphere contains ten speakers. DX EDIT, Toronto, 2017
INTEGRATING SOUND IN LIVING ARCHITECTURE SYSTEMS
1. Categorizing speaker constellations in type and function to gain control over precise sound projection.
2. Introducing irregular speaker configurations to cater to irregular sculptural configuration.
3. Making virtual sound objects, actuators, and sensor interfaces part of the same virtual space and enabling integrated interaction.

Exterior and Interior

Embedding a distributed network of speakers within the sculpture required a redefinition of the 4DSOUND panning algorithms. The new algorithms expand sound spatialization within a singular omnidirectional grid, hence a distinction between exterior and interior speakers was necessary.

A field of exterior speakers can be considered similar to 4DSOUND’s regular layout. It covers the omnidirectional field of the actual space and virtually extends this field beyond the actual space to infinity by adding spatial sound synthesis. 4DSOUND’s equally distributed grid system provides a social listening area that is not concentrated into just one sweet spot. The listeners are empowered to move around to self-compose experiential perspective and orientation.

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The interior speakers are the voice of the sculpture. The configuration of the sculpture’s components and their spatial relations impact how the 4DSOUND interior speakers are set up and run as internal constellations. In projects that have been realized to date, we have successfully generated sounds that behave like a dense crackling neural network, or the omnipresence of smaller objects within the sculpture - like electronic birds in a tree.

For the most part, sounds in either one or both of the fields share the same extensive set of controllable parameters to form movement, physics and perception of sounds in space. In terms of control, this added sonic versatility to
cover both the internal and external fields of different sculptures’ components requires only a minor expansion in parameters. A simple matrix interface allows one to route sound sources to the desired speaker constellations. Sounds that live within the one sculptural composition can easily be transferred to or spread over other components. Indirect connections are also possible, like external reflections as responses to sounds that originate from inside can potentially create echoes that seem to come from spaces that are beyond the one that the listeners are in.

For the installation *Astrocyte* (2017) we introduced the Sphere Engine, a prototype application that complemented the regular 4DSOUND Engine. The Sphere Engine was designed to drive ten speakers inside the large sphere that created the central constellation of the installation. The speakers were spread almost equally across the central semi-sphere, which was slightly tilted and raised above the heads of the listeners. The result was a defined focal listening point within the expanded space of the sculpture. This centralization, together with the gentle directional quality of the speakers and granular sound design, evoked a sensation of proximity and a feeling of intimacy with this large, radiating object.

We found that the results of technical sound tests - such as exposure to continuous noise and a variety of waveform pulses to different spatial projection onto the sphere - offered a broad palette of characters and
abstract associations. For example, synchronised pulses can accentuate the shape of the sphere as a whole, where diffracted sounds dissect its parts and reveal the granularity of inner processes within the sphere. As a result of high speaker density the perception of small, moving sound objects became extremely clear. Altogether, the sphere created a 'sonic painting' with a broad palette onto a tightly focused frame.
Irregular Speaker Configurations

4d.pan, the proprietary panning algorithm developed by 4DSOUND, was initially limited to symmetrical rectangular speaker grids. To provide asymmetrical sculptures with varying densities of interior speakers, we expanded the 4d.pan algorithm to support irregular setups of varying sizes and shapes. The principle remains to position exterior field speakers as equally spaced as possible to assure balanced sound projection and refined continuous spatial definition in all directions. For the interior, all configurations are allowed in order to support any artistic or acoustic tasks and to create more irregular grids. A combination of an equally spaced exterior field with an irregularly spaced interior determined by the sculpture can deliver a convincing and powerful soundscape with explicit control over the sonic presence in the space.

Any given constellation of speakers can be divided into subsets to allow extremely detailed control in spatial sound design. The setup differentiates speaker groups (areas) for sound sources to exist within. The internal structure of the sculpture divides interior speakers in ways that mimic its components. This results in an almost organic design where the sonic and material interpretation of the sculpture dictates the speaker configuration, instead of the other way around. We are excited that backend complexities can realize an elegant frontend for an intuitive system handling and sound design.

The permanent environment Amatria (2018) at Indiana University is a follow up on the Astrocyte installation (2017). The environment consists of ten speakers distributed throughout the larger part of the sculpture. We identified the Large Sphere (speakers A1-A3), the Small Sphere (speaker B1), and the Canopy (speakers SF1-SF6). By defining three sub constellations we were able to develop the spatial sound design around two actor objects (the Spheres), and a more diffracted area (the Canopy).

As the protagonist, the Large Sphere is equipped with three speakers, while the Small Sphere has only one. The differentiation made possible by using a triad configuration creates a spatial depth and dimensional perception of the sounds that are projected onto the field. The single speaker in the Small Sphere is timid compared to its neighbours, but the sharp contrast in sonic magnitude and its distinctive character makes it a focal point within the shared space.
While designing the spatial sound for the installation, we experimented with unique assignment for each character in the sculptures. For example, ‘breathing’ spheres would have subtle reflections on the canopy with patterns resembling textures of dense fog, light raindrops or breaking glass. The flexibility of the system in filling the entire space or carefully occupying specific areas proved to be essential in constructing the integration of sculpture and sound.

*Image 7* Excitor Objects and their distance-based relationships to actuators present in a sculptural environment.
Another important R&D goal has been the integration of sound spatialization with other kinds of actuators in the sculpture such as granular light, kinetic mechanisms and sensor interfaces. To create meaningful integrated interaction, we developed the prototype Distance Based Interaction Engine (DBIE) in collaboration with LASH collaborators Philip Beesley, Rob Gorbet and Adam Francey. The DBIE is a simplified interpretation of the spatialization algorithms that already exist within 4DSOUND. In the 4DSOUND Engine, spatial properties of virtual sound objects are mapped to speaker amplitudes and audio signal processing (spatial synthesis). Meanwhile, the DBIE maps basic spatial properties of an ‘Excitor Object’ like position, size, and force to lights, kinetic objects, or any type of actuator.

The basic principle of Distance Based Interaction is the intensity of an actuator (e.g. the brightness of a light, or the speed of a motor), which is determined by its distance to a virtual object. Every actuator holds position properties that match their actual locations relatively within the sculpture. The virtual Excitor Objects also live inside this 3D map where their presence can excite the actuators by moving closer and further away. An excitor can be an infinitely small point, or of any spherical size. An increase in scale means it covers more virtual space and effectively comes closer to more actuators resulting in more actuators being excited. The final parameter is Force, a multiplier of Distance Intensity acting as the upper limit of excitation. With scale and force combined, one can create a large but weak excitor, or a small and strong one.

Sensor systems are integrated in the same Cartesian space as the sound objects. Their positions in an infinite continuum of space are defined by XYZ-positions. Infrared modules register the presence of visitors and their positions inside the sculpture, as well as their hand gestures. Virtual sound objects and excitors can react consistently and immediately in attractive or repulsive reflexes triggered by infrared sensors. There is a subtle balance between direct basic responsiveness (e.g. triggering short samples on the location of the sensor) and more complex movements that evolve over time (e.g. ripple effects in the surrounding actuators, or the progression of the sound composition on a higher level). The correlation of sound events in space and actuation triggered by movement and behaviour enhances the immersive experience between the visitors and the sculpture.
In this setup, virtual sound objects, virtual excitors, speakers, actuators, and sensors all share the same environment, and can interact accordingly. This produces a versatile and intuitive interface to design coherent movements and behaviour. Background behaviour can be small excitors, moving fast and slowly, emerging and vanishing like snowflakes or a soft breeze through the woods. Bigger excitors could be phantom creatures, or abstract magnetic forces beating through space. The technical essence is that single indexed actuators are no longer considered in artistic design, instead, the interface is elevated to a higher level of control where conceptual translation becomes more immediate and inspirational.
The first implementation of the DBIE was in *Noosphere* and *Aegis* (2018) at the Royal Ontario Museum in Toronto, Canada. Background behaviour was generated by small, semi-random excitations throughout the sculpture. In the larger sphere *Noosphere*, an excitor was active with transformational size, force, and trajectory. They marked the first modest but profound step in unifying algorithms for behaviour in sound, light, and movement, and in interaction with human input through sensor interfaces.

**Future Research**

In future research we will refine panning algorithms, explore the characteristics of different kinds and combinations of speakers, and continue stretching the flexibility of sound spatialization using varied speaker configurations. The divide between exterior and interior sound may be further contrasted to enhance depth of field. At the same time, the differentiation will also invite explorations in the coherence between the perception of diffusion field and focused objects, emerging from the same technological principles in hardware and software.

A shared origin with all technological disciplines in the same spatial interaction paradigm will be further developed in an even more integrated software reality. A right balance between utilising processing power of a personal computer and performing algorithms on the distributed network of microprocessors that are not necessarily aware of structural properties, can enable each sculptural character to act more like individual agents within the network.

Other objectives are designing an offline prototyping environment to develop interactive algorithms and behaviours that can develop independently from a hardware testbed. Since all virtual properties will share the same physical environment, they should be included in a shared virtual environment. An extensive 3D visualization of all activity will complement the possibilities to exploit spaces as an instrument and provide insightful feedback. The tool will allow detailed preparatory work, stimulate creative design of the space as a whole, and increase efficiency during the final phases of installing the sculpture on site.
4DSOUND was founded in 2007 by composer Paul Oomen and technologists Poul Holleman, Luc van Weelden and Salvador Breed to further the development of new processing software and control interfaces for spatial sound. In the same year, audio engineer Leo de Klerk published his patented application for omnidirectional loudspeakers that enable the production of phantom sound images independent of the place of the listener. Since 2010, Oomen and de Klerk have worked together on the development of the system.

4DSOUND is a fully omnidirectional sound environment where the listener can experience sound in an unlimited spatial continuum. Sound can move infinitely far away or come intimately close: it moves around, as well as above, beneath, in between or right through you. Led by your ears, you’re encouraged to explore the space. You can move between blocks of sound, touch lines of sound and walk through walls of sound. 4DSOUND enables vivid sonic environments that blur the boundaries between the real and the imagined: the world of sound we know, and a world beyond.