The ZKM Klangdom

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ABSTRACT

The Klangdom is an audio spatialization instrument developed at the Institut für Musik und Akustik at the ZKM. It is made up of 39 Meyer Sound loudspeakers hung on four sliding tracks, allowing for easy re-configuration of the speaker setup. The audience sits inside the Klangdom, which can be controlled either directly via a mixer, by externally developed software, or by a sequencer for sound movement, Zirkonium, developed at the ZKM. Zirkonium can accept and spatialize audio generated by other applications (even on remote machines) and can simulate the Klangdom over alternate speaker setups to aid composition and dissemination (e.g., in stereo or 5.1).

Keywords

Sound Spatialization, Ambisonics, Vector Based Additive Panning (VBAP), Wave Field Synthesis, Acousmatic Music

1. INTRODUCTION

At the Institut für Musik und Akustik (IfMA) at the ZKM | Zentrum für Kunst und Medientechnologie Karlsruhe, we are focused on commissioning, producing, and presenting electroacoustic music. To this end, we have a variety of ateliers, studios, and concert spaces, one of the better known being the Blauer Kubus (the Blue Cube), which is the IfMA's configurable environment for concerts as well as a sophisticated production facility. The Kubus has always been well equipped for presenting music in standard formats such as quadraphonic, 5.1, octophonic, or 16 channels. Though we have in the past had some speakers hung overhead, above the audience, the majority of the loudspeakers were positioned around the outside edge of the Kubus, limiting our ability to create a completely immersive sound experience. Moreover, as the number of channels increases, the control of a multi-loudspeaker environment seems to call for a different instrument than a mixing console. It was the desire to create such a system which led to the Klangdom project.

2. HISTORY

The spatial distribution of sound events is a parameter used in many musical genres and has played an important role in electroacoustic music in particular since its very beginnings.

As early as 1951, the studio at the Radiodiffusion-Télévision Française (RTF) employed a quadraphonic spatialization system with two front channels, one channel in the back, and one above the listeners and developed a controller for the system, the *pupitre d'espace*[16]. The pupitre d'espace was used as an instrument for live control of spatialization. As we can see in this example, spatialization is accomplished through the inter-working of three different components: loudspeaker position, technique for routing sound to the loudspeakers, and a controller for positioning the sound sources.

Figure 1. The Blauer Kubus

A thorough description of the development of multi-channel sound in electroacoustic music is unfortunately not possible in the space permitted. We refer the interested reader to Zvonar 2005[16] and Küpper 1984[9] for discussions of various aspects. To summarize the developments, we can broadly observe two approaches develop which we will label the acousmatic approach and simulation approach.

The acousmatic approach can be thought of as an extension of musique concrète. Similar to how musique concrète focuses on the capabilities of the tape machine as a source of generating musical material, the acousmatic approach focuses on the loudspeaker and its qualities as a way to organize sound in space. This is best illustrated by the acousmonium[3], developed at GRM in the mid-1970s. An acousmonium is made up of different types of loudspeakers distributed throughout a room. An acousmonium is usually played live by a composer/performer who routes the audio of a piece (often 2-channel) to the different loudspeakers, taking advantage of the sound reproduction characteristics and physical placement of the loudspeakers to realize a live performance. Another system with a similar philosophy is the sound dome of the sort championed by Leo Küpper[9] and exemplified by the German Pavilion at the World Expo '70 in Osaka, Japan. Though a sound dome is typically assembled from one particular brand/model of loudspeaker, in both it and the acousmonium, the composer/performer does not directly control sound position in 3D space as a parameter — rather she controls the routing of the sound to loudspeakers, which by their very location define the virtual position of the sound source.

The simulation approach, by contrast, uses 3D space as parameter, hiding the internal routing to the loudspeakers and uses signal processing and psycho-acoustic properties to produce the illusion of a sound emanating from a particular point. Whereas the acousmatic approach can be realized in the analog domain with just a mixer, the simulation approach more or less requires the intercession of a computer. One of the early pioneers of this approach was John Chowning, who in his 1971 article[2] described techniques for simulating moving sound sources over a quadraphonic speaker setup. The Spatialisateur or Spat[7] developed at IRCAM is an evolution of this idea and lets the user specify a sound source's position as well as its reverberation characteristics, which are also important for the perception of sound localization.

Other recent work along the same line has focused on Wave Field Synthesis and Ambisonics. Wave Field Synthesis[4] uses a large number of small loudspeakers to synthesize an approximation of the wavefront that would be observed were there a sound source at the specified position. Ambisonics similarly approximates the sound field at a point, but does so using ordinary speakers[6].

3. CONSTRUCTION

The goal for the Klangdom was to be able to bathe listeners inside the Kubus with a wash of sound from all directions. To accomplish this, it was important that we be able to place loudspeakers around the public, covering the entire 360 degrees of azimuth and 90 degrees of zenith (the top half of a sphere). However, flexibility was also a key consideration. We wanted the placement of loudspeakers to be configurable and the individual components to be usable outside of the Klangdom.

Figure 2. The Interior of the Kubus

Since we were working with an existing space, the Kubus, and did not have the luxury of building a new space for our spatialization environment, practical requirements played a major role in the design. Any infrastructure we built needed to augment and play well with our existing capabilities. This determined our choice of loudspeaker and scaffolding for the dome.

3.1 Speaker Type

Several factors influenced our choice of speakers. First of all, we wanted the flexibility to use the speakers in the context of both a simulation as well as an acousmatic strategy. We also wanted to be able to achieve concert volumes without having multiple loudspeakers project the same signal because of the resulting sound coloration. Additionally, we have a heavy schedule of concerts and guest artists and can always use a few extra concert loudspeakers. Thus, one of the main requirements was that the loudspeakers be powerful and of a good enough quality to be usable outside of the spatialization system. We settled on Meyer Sound UPJ-1 as a high-quality speaker. We have 33 UPJ-1, augmented with four CQ-1 and two CQ-2.

Using these speakers ruled out Wave Field Synthesis, since WFS functions best with small loudspeakers.

3.2 Speaker Positioning

A requirement for the Klangdom infrastructure was that it permits the loudspeakers to be quickly moved. There are both theoretical and practical reasons for this requirement.

First of all, given the range of music we present, we need to be able to accommodate a variety of loudspeaker setups. Though the default setup for the Klangdom is a "balanced" arrangement of speakers (more on this below), a composer may intentionally, for artistic reasons, desire an alternate speaker setup.

Additionally, works we present in the Kubus may have a visual component. We need to be able to rearrange the speakers to ensure that the visual aspects are properly represented — e.g., allowing the projector unfettered access to the projection screen. And since one concert program may involve works requiring different speaker setups, the Klangdom needed to be reconfigurable quickly, within the time allotted by a brief intermission.

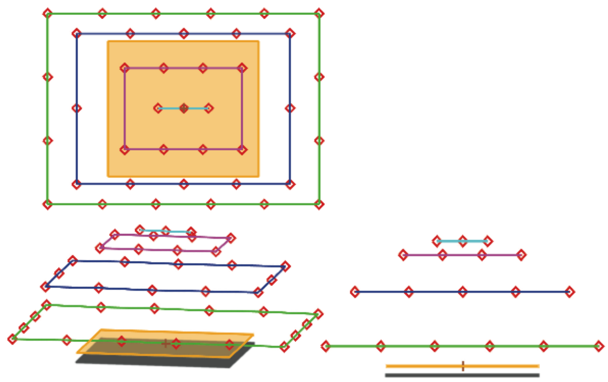

Figure 3. Distance-oriented distribution of speakers

Though quick reconfiguration and support for exotic setups was a consideration, we wanted the Klangdom to also be able to accommodate the ideal loudspeaker setup. What is the ideal loudspeaker setup? The answer is dependent on the technology employed for sound spatialization as well as compositional aims, but one reasonable answer is to distribute loudspeakers as "equally" as possible over the surface of a sphere. This is known in mathematics as a spherical code[14] and is, for example, the approach taken by Ambisonics[13].

However, distributing the speakers on the surface of a sphere is at odds with the geometry of the Kubus. As the name suggests, the Kubus is a rectangular prism and to build a spherical structure inside it would result in a considerable amount of unusable space. One option would be to distribute the speakers over an ellipsoid, as done by Küpper in Linz, but constructing curved rails to hang the loudspeakers upon proved to be considerably more expensive than building straight ones. Thus we decided to work with the geometry given by the Kubus and distribute the speakers on tracks parallel to the walls of the Kubus. Within these requirements, we created two canonical configurations — one distributes the speakers evenly in space (the distance between two speakers), the other evenly with respect to the angle between two speakers.

Figure 4. A Klangdom trolley

We built three rings, along with one straight segment directly overhead, upon which to hang the loudspeakers. The two outermost rings are comprised of track into which we can insert a trolley. The speakers are attached to the trolley by two cables to prevent them from rotating unwantedly. The speakers on these two tracks can easily be shifted laterally. The innermost ring is a one-piece ring, which does not facilitate the easy lateral movement of the speakers, but can be raised or lowered via a winch.

4. CONTROL

In keeping with our motto of flexibility, we have tried to stay as open as possible with regards to control for the dome. Although Wave Field Synthesis cannot work well with the given hardware, we can support other standard panning algorithms, such as Ambisonics and Vector Base Amplitude Panning (VBAP)[12].

Since the loudspeakers have built-in amplifiers, they are attached directly to a Yamaha DM2000 mixer and any computer with an audio interface capable of feeding 39 channels can connect to and drive the system. Thus, if a composer/performer comes to us with her own preferred spatialization software, she can easily plug that in.

However, for the cases where the composer does not have spatialization software prepared, we have developed our own software solution, Zirkonium.

4.1 Zirkonium

Zirkonium is software for sound spatialization based as heavily as possible on components provided by Apple as part of CoreAudio[1]. This ties us to Apple hardware but allowed us to develop the software more quickly, incorporating more functionality, than if were to have taken a cross-platform approach.

To use Zirkonium, the user defines a set of resources they want to pan. A resource is compromised of one or more channels of audio and may come from a sound file (AIFF, WAV, MP3, AAC, among other formats), from an audio interface, an AUNetSend input (an AudioUnit plug-in[1] that receives audio over a network) or a Jack[10] source. Having AUNetSend and Jack sources make it possible for other programs such as a digital audio workstation (DAW), Max/MSP, or SuperCollider to send audio into Zirkonium.

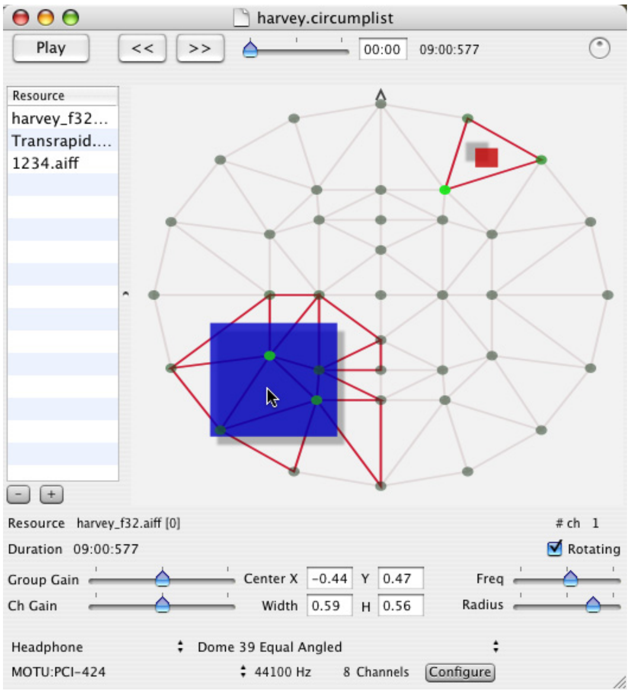

Figure 5. The Zirkonium interface

Once in Zirkonium, each channel of a resource is made available as a sound source which can be panned around the dome. We employ a panning technique that we have developed and call Sound Surface Panning (SPP). SPP is not actually a panning algorithm itself, but a technique for expanding the capabilities of an underlying panning algorithm such as Ambisonics or VBAP. Ambisonics and VBAP are oriented to controlling the position of point sources. SPP extends the underlying panning algorithm to make "sound size" a variable of control. Though a better solution needs to incorporate decorrelation [8][11], SPP takes a naive approach and decomposes a "rectangle source" into a mesh of points regularly distributed inside the rectangle, applies the underlying panning algorithm to these points, and then scales the output so the resulting acoustic power remains 1.

Using SPP, each sound source has 4 control parameters: X and Y position and width and height. These may be controlled in the GUI with the mouse, by a HID controller such as a joystick, or from another program via OSC[15]. Zirkonium can also read a panning score file and schedule the events described therein. We have also created a plug-in to control the pan parameters from within a DAW, better integrating spatialization into the composition process.

As hinted above, AudioUnits can also be hosted in Zirkonium. The Apple 3D in particular is utilized to facilitate some of the software's functionality. Zirkonium can produce a mix designed for listening over headphones or a 5.1 setup. This is done using the Apple 3D Mixer and specifying one of HTRF, Kemar Head, or 5.1 as the spatialization target and setting the positions of the loudspeakers as the locations of virtual sound sources. Such a mix may not be optimal for all purposes, but it may nonetheless be useful.

5. FUTURE WORK

Our work with the Klangdom is still in the early stages. Given our flexibility in loudspeaker positioning, we plan to investigate the utility of various loudspeaker configurations. One aspect of this work is to characterize the distortion incurred because of the non-ideal position of the speakers and look for ways to improve this. We also intend to investigate loudspeaker setups that have a psycho-acoustic foundation, rather than a pure mathematical one. Continuing the development of the SPP technique is something else that we see as important. For example, we are looking at ways to incorporate decorrelation. Designing and utilizing controllers is another area of research we are undertaking. As mentioned above, HID devices can be used to control the Klangdom and we would like to take advantage of force-feedback and haptics as a means of making the use of the Klangdom instrument more natural. To this end, we have also begun the design of tangible interfaces for controlling the Klangdom and expect to see interesting results. In the near future, we will be commissioning composers to realize compositions for the Klangdom. We expect the experience of working with composers using the system will bring about new insights, challenges, and changes.

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