# REAL-TIME SPATIAL PROCESSING AND TRANSFORMATIONS OF A SINGING BOWL

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## ABSTRACT

We propose different real-time spatial-modal manipulations of a physical model of a singing bowl. The high number of degrees of freedom in the model, combined with spatial processing algorithms, provides the possibility of obtaining rich and expressive transformations.

## 1. INTRODUCTION

Singing bowls are musical instruments that have recently seen an increasing interest in sound synthesis. Physical models of singing bowls based on digital waveguide networks have been developed [1] to be driven by a real-time controller [2], and have been used in computer music pieces such as *Prayer for John Pierce* by Matthew Burtner and *Requiem Moksa* - for 12 vocalists and 4-channel tape by Ching-Wen Chao. Also, a banded waveguide of a singing bowl has been included in the release 4.0 of the Synthesis Tookit [3].

In this paper we are interested in exploring the sonic possibilities offered by considering the bowl as an acoustic resonator. We started from a real-time physical model of a singing bowl, and we processed it in different ways, as shown in the following sections.

## 2. RECORDINGS OF THE BOWL

Figure 1 shows the Tibetan bowl that was used as a starting point for our project. We recorded the impulse response of the bowl when hit by a force hammer. The recordings were made by hitting the bowl in different locations, as illustrated in figure 1. Additionally, for each impulse location the microphone was placed in three different positions: inside the center of the bowl, outside the bowl, on top at about 30 cm, and outside in the side, at about 20 cm.

Figure 3 shows the spectral variations that result from moving the microphone position. Figure 2 shows the spectral variations obtained by changing the position of the excitation.

These variations, although perceivable, are not significant for the purpose of our paper. The idea of interpreting the bowl as an acoustic space in which the listener moves and the spectral components of the bowl change according to his or her movements are not perceivable enough if we maintain the physicality of the real instrument.

For this reason, we extended the bowl model allowing more flexibility both in the resonator and in the excitation, as described in the following section.

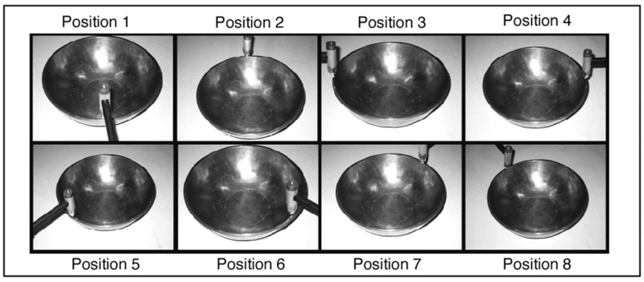

Figure 1: *The figure shows the eight different positions in which the bowl was hit during the recordings.*

## 3. MODELING THE BOWL

### 3.1. Modeling the resonator

In order to model the resonator, we used eight digital waveguides connected in parallel, each one representing one mode of the bowl. This model is a generalization of the one described in [1], in order to allow more flexibility to perform different spectral and spatial manipulations.

Each waveguide is coupled to a second order resonant filter that models the decay time of the corresponding mode. In order to extend the resonator, we allow each mode of the bowl to be controlled independently. In order to change the characteristics of each mode, we inserted other filters, connected in series, into the digital waveguide structure.

A first order low-pass filter is used to control the damping characteristics of each partial together with its harmonic. The role of the low-pass filter is similar to the one of the bandpass filter, except that it allows the possibility of maintaining the higher order harmonics of the resonator, a possibility neglected using only band-pass filters. We choose the simplest low-pass filter given by the difference equation

$$y[n] = ax[n] + (1-a)x[n-1], \tag{1}$$

where the filter coefficient $0 < a \leq 1$ can be controlled in real-time. A first order all-pass filter is used in order to shift the position of the partials of the resonators. Figure 4 shows the block diagram structure of one mode of the extended bowl. In it, the dotted blocks represent parts of the models that can be omitted. In order to obtain the spatial processing described in the following sections, each mode of the bowl can be either controlled independently and sent to one of the eight channels of our system, or summed to the other modes. Figure 5 shows the complete structure of the instrument. As before, the dotted blocks represent parts of the models that can be omitted.

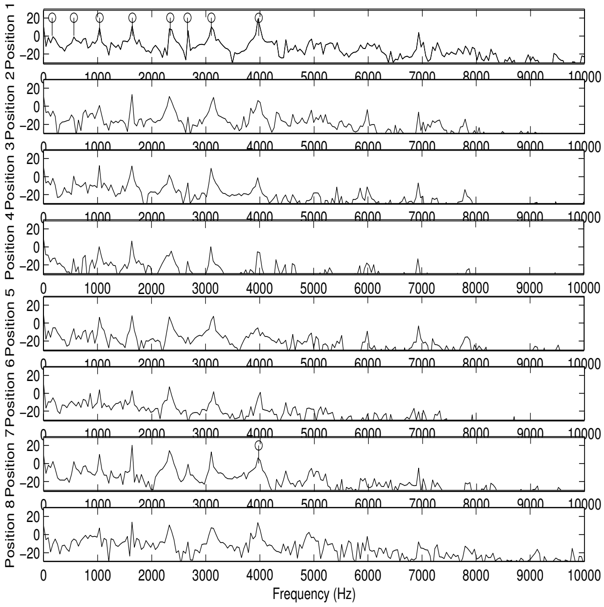

Figure 2: *Spectra resulting from varying the excitation position of the bowl. From top to bottom the plots illustrate positions from one to eight respectively, according to figure 1. In the first position the location of the eight modes is also represented. The evolution of the modes according to the hitting positions can be seen.*

### 3.2. Modeling the excitation

The waveguides can be excited with a sustained or a transient source of energy. In the case of the sustained excitation we modeled a feedback and a feed forward energy source. The feed forward source is an external energy that is continuously injected into the system. Interesting examples with which we experimented are noise bursts or the residual of a musical instrument. The feedback source models two kinds of excitations: blowing into the bowl and bowing the bowl.

These last two kinds of nonlinear feedback interactions were obtained by implementing a velocity dependent friction model and a pressure dependent blowing model. The coupling between the linear propagation of waves in the bowl and the nonlinear excitation was performed using the classical graphical solution introduced by Friedlander and Keller in 1953 ([4]).

The model can therefore be used either as an acoustic resonator, when a source of energy is fed into the structure, or as a linear system that is connected to a nonlinear exciter.

## 4. IMPLEMENTATION

We implemented our instrument as an extension to Max/MSP called *blowl*∼. Since the maximum number of inlets allowed by Max/MSP is 32, we chose to implement the following control parameters: 8 fundamental frequencies, 8 decay times for the low-pass filters, 8 bandwidth for the resonant filters, 4 dispersion coefficients for the allpass filters, one inlet to input an external source of energy, one excitation position (i.e. where the bowl is hit), one excitation pressure (i.e. how hard it is hit) and one excitation velocity, and 8 outlets (each outlet corresponding to a mode of the resonant structure).

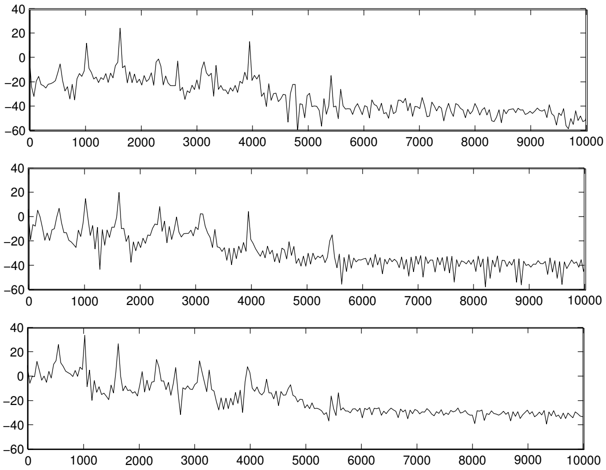

Figure 3: *Effect of moving the microphone: top:outside on side, center: on top in center, bottom: inside the bowl .*

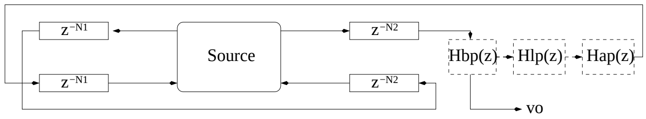

Figure 4: *Block diagram structure for one mode of the extended bowl. The dotted connections mean that the corresponding block can be omitted in the structure.*

The large combination of input parameters offered by the model allows the possibility of obtaining interesting and rich sonorities.

## 5. REAL-TIME SPATIAL PROCESSING

### 5.1. Reinterpreting Acoustic Body as Acoustic Space

Because the primary goal of physical modeling has traditionally been to recreate sounding physical bodies, these techniques have largely dealt with the exteriors of bodies, the perceived sound of the listener from the outside. However, in many multichannel sound diffusion environments the listener is ideally placed at the exact center of the space, occupying the interior of another resonating body, the room.

In an attempt to extend the physical model we have brought together the notion of ”body” as perceived from an exterior, and the perceptually interior notion of ”space.” This juxtaposition allows for an extended notion of the objecthood of the model, and the possibility of transforming it from body into space, or from object into environment.

We create the possibility of moving from the outside to the inside of the bowl by taking the impulse response of different locations on, around, and inside the bowl, and isolating the different

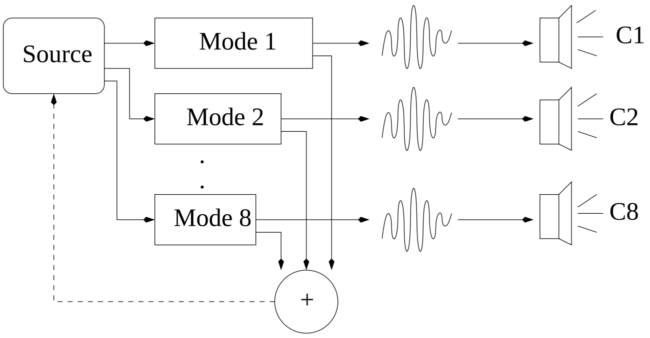

Figure 5: *Total structure of the extended bowl. The dotted connection between the exciter and the resonator mean that there can be feed-forward or feedback connection between the two respectively. Each mode of the bowl is sent to a different channel. Modes can also be added together so that different modes can be output to the same channel .*

characteristics. In this way we can move the perceived point of the listener from an exterior position to an interior position while simultaneously manipulating the spatial diffusion of the eight modes through a multi-channel speaker array.

### 5.2. Extended Objecthood and Extended Techniques of Physical Models

In previous work, the authors have explored extended techniques for physical models by taking advantage of the disassociation of the synthesis and control aspects of the virtual instruments [5, 6, 7]. The modal transformations of the bowl described here represent a similar desire to explore extended techniques of physical modeling synthesis, in this case using techniques of spatial processing. In both projects the possibilities of the embodiment of the model are being broadened. The virtual body is not confined to the same limitations as the physical body, and extended techniques are explored by blurring the boundaries between resonating body and acoustic space.

We are interested in uncovering what happens when the body of the model, an instrument that was originally perceived from the exterior, becomes the space itself and the listener is moved into the interior of the virtual instrument. The singing bowl provides an ideal vehicle for experimenting with the effect of this transformation due to the spatial positioning of the resonant modes. The multi-channel diffusion of the modes stresses the coherence of the model, psychoacoustically pulling apart the synthesis into constituent parts as the components are treated separately in space.

This is an excellent example of the more general technique, Spatio-Operational Spectral Synthesis (S.O.S.), described by the authors in another paper [8]. SOS questioning the integrity of spatial perception utilizing the psychoperceptual interpretation of audio objecthood as a result of streaming theory[9].

In instrumental extended techniques of any kind, it is not important for the resulting sound to coincide with the our normal association to the sound of the instrument. Rather, the extended technique is one that pushes the acoustics of the instrument into an extreme state, seeking precisely those sounds that are natural to the instrument but also unfamiliar to the instrument's normal production. With extended techniques for physical models, the possibilities of extension allow for sounds quite outside the recognized pallet of sounds available to the acoustic instrument. As in the acoustic counterparts, limitations are imposed by the synthesis parameters of the model.

In acoustic instruments the physics of sound governs the production of extended techniques, while in synthesized instruments, the synthesis parameters themselves determine the range of extended techniques. While a physical model is indeed a model of a real physical body, the extended techniques allow the user to consider the unique acoustic properties of the computer-generated instrument independent of its real-world counterpart. The extended techniques of the real-world instrument and those of the virtual-world instrument can and will vary widely even if the two sound exactly the same when given the same control data. Thus in compositionally extending the bowl model, it is not important to maintain the coherence of physical properties. The questioning of these physical properties is more interesting to the composer.

Furthermore, despite the fact that physical modeling synthesis grew from a desire to emulate real world instruments, the composer is more interested in these instruments for their own unique characteristics, not for their ability to approximate a real instrument. The attraction to physical modeling for the composer is that these new instruments contain the richness and controllability of physical instruments. The desire for this less constrained physical model instrument is precisely what has driven the development of projects such as the BaBo generalized resonant model [10]. Davide Rocchesso has described the problem succinctly:

> *"The classical computer music utopia that implies having the power to do everything seems to be contradicted by the physically based approach. Therefore computer musicians, most of whom are "utopists", keep using frequency modulation or granular synthesis as general tools for forming musical material."*

Where Rocchesso approaches the problem using generic models, our approach to has been to allow the models their own range of extended techniques while maintaining the synthesis similarity to the instrumental physical body. In this way we use the notion of modal synthesis to extend the concept of embodiment.

### 5.3. Spatio-Modal Processing

As described above, the objecthood of the bowl is fundamentally altered by situating it on the threshold of streaming, between modal unity and multiplicity. This is accomplished by allowing each of the eight modes to be controlled independently from user input, and processed separately on output. We explore possibilities of spatial processing of the modes of the bowl, focusing on the audio effects of spatio-resonant transformations. Using multiple MIDI input devices we have the possibility of controlling both the input parameters of the bowl and the diffusion in space. The extensive number of parameters that need to be controlled in real time requires the use of an array of controllers if it is desired that all parameters be controlled by human input. For prototyping the system we used one or two 16 channel multi-slider continuous controllers. Further, by placing the spatial processing and modal processing under the same controller we can synchronize the frequency of the mode with its spatial position. As the frequency changes the space is also modulated. Amplitudes are calculated for each channel using the following Cartesian distance formula:

$$Amp[c] = MAXAMP - \sqrt{(x[c]-x)^2 + (y[c]-y)^2} \quad (2)$$

where $c$ is the channel number. In it, $Amp[c]$ is the amplitude for channel $c$ and $x[c]$ is the $x$ coordinate for channel $c$. Similarly $x$ and $y$ are the respective $X$ and $Y$ coordinates for the given audio stream. where c = channel 1-8. For example, Amp[c] is the amplitude for channel c and x[c] is the x coordinate for channel c. Similarly x and y are the respective X and Y coordinates for the location of the given audio stream.

Figure 6 details the implementation of this configuration.

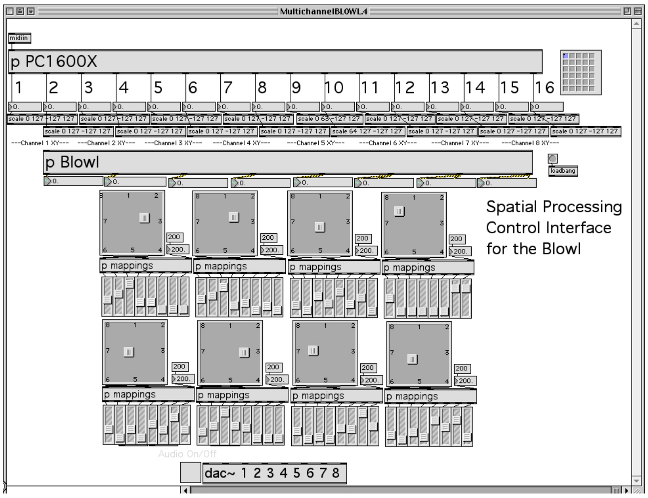

Figure 6: *Max/MSP interface for the* blowl $\sim$.

## 6. CONCLUSION

The singing bowl physical model lends itself very well to spatio-operational processing because the multimodal interactions are closely tied to physical locations on the bowl. Modal transposition of the bowl changes its shape and size. By linking the notions of transformative body and transformative space we have evolved an approach to physical models combining modal synthesis with the concept of embodiment. In addition to future work in composition and signal processing, we believe the joining of multichannel diffusion with extended physical models offers possibilities for a new approach to aesthetics involving theories of embodiment and objecthood.

## 7. REFERENCES

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