AQUARIUM SONIFICATION: SOUNDSCAPES FOR ACCESSIBLE DYNAMIC INFORMAL LEARNING ENVIRONMENTS

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ABSTRACT

Museums, science centers, zoos and aquaria are faced with educating and entertaining an increasingly diverse visitor population with varying physical and sensory needs. There are very few guidelines to help these facilities develop non-visual exhibit information, especially for dynamic exhibits. In an effort to make such informal learning environments (ILEs) more accessible to visually impaired visitors, the Georgia Tech Accessible Aquarium Project is studying auditory display and sonification methods for use in exhibit interpretation. The work presented here represents the initial tool building stage. We discuss the sonification system we are developing, and present some examples of the soundscape implementations that have been produced so far.

1. ACCESS TO INFORMAL LEARNING ENVIRONMENTS

Among the common goals of informal learning environments (ILEs), including museums, science centers, zoos and aquaria, are the education and entertainment of the visiting public. However, as the number of people with disabilities living in the community has grown, and as public environments have become more accessible to them, ILEs are faced with educating an increasingly diverse visitor population with varying physical and sensory needs. Although architectural suggestions such as the Americans with Disabilities Act Accessibility Guidelines (ADAAG) have improved facility access [1], these requirements are primarily intended to facilitate access for people who use wheelchairs and even then, are too general to apply directly to exhibit design [2]. In comparison to ILE visitors with hearing or physical impairments, visitors with vision impairments can expect the lowest level of exhibit accessibility. In fact, in a nationwide survey of ILEs, the majority of respondents (51%) reported that *less than one-quarter* of their exhibits were accessible to visitors with vision impairments [3]. Therefore, it is not surprising that many individuals who are blind report that they either do not visit ILEs at all or do so infrequently, because there is "nothing for them, nothing accessible" [4].

In response to the lack of guidance that would enable ILEs to provide more accessible exhibits and exhibit interpretation, particularly for visually impaired visitors, a group of researchers at Georgia Tech have begun to study methods of using auditory display to provide some access to the dynamic exhibits. The work of the "Accessible Aquariums Project" applies equally to aquaria, zoos, natural science museums, and other dynamic ILEs. The first technical stage of the work is to actually track fish, sharks, lions, molecules, or whatever is moving in the exhibit. This is being tackled with a mixture of computer vision and electronic tracking devices. Once such a 4-dimensional data stream (3D plus time) is created for an exhibit, we can then drive a multimodal display. The work presented here shows the initial stages of developing tools and methods of mapping fish movement to sounds, with the idea of providing some non-visual information about the attributes of the various fish being tracked, as well as their location and activities. Once the tools are in place, we will continue our systematic approach to exploring the auditory design space. We will evaluate the effectiveness and aesthetics of our soundscape with a broad range of potential aquarium visitors, including in vivo studies conducted in partnership with the new Georgia Aquarium.

1.1. Auditory Displays in ILEs

Despite the lack of specific guidelines, audio technologies have been used for over 50 years as a primary mode of providing access to interpretive information for ILE visitors who are visually impaired [5]. From the basic technologies like audio labels and tape recordings, to the more innovative approaches of using cell phones [4, 6], MP3s [6], and Podcasting [6], information can be conveyed in various modes and layers. Although many of the recent advances in audio technologies have focused on the medium or the hardware for delivering audio content, several software interventions such as random-access, "audio branching", and wayfinding have been explored to provide users with more flexibility [4, 5]. Much of the audio interpretation used to date has simply been narration of exhibit signage rather than audio descriptions that would convey visual information about exhibits and their artifacts. Exhibit dynamics have not been addressed. Non-speech audio and sonification, shown to be useful in many domains, have been almost completely ignored.

2. SONIFICATION SYSTEM DESIGN

We have taken a flexible data-to-sound mapping approach that will accommodate a range of data types, exhibit events, and resulting auditory outputs. The engine for our sonification is built on Max/MSP. For the first round of designs we have based our design on a musical foundation, since this is quite familiar to many ILE visitors. However, the system is able to use all manner of sounds as building blocks. Figure 1 shows an example of a Max patch that creates pitches using a rhythm based on a table of probabilities. Our patch takes the three dimensional data from the fish in the aquarium and creates musical information based on different attributes of the fish and their environment. These data are then passed on to the Reason software via MIDI (Musical Instrument Digital Interface) channels. Reason is an extremely useful sequencing program

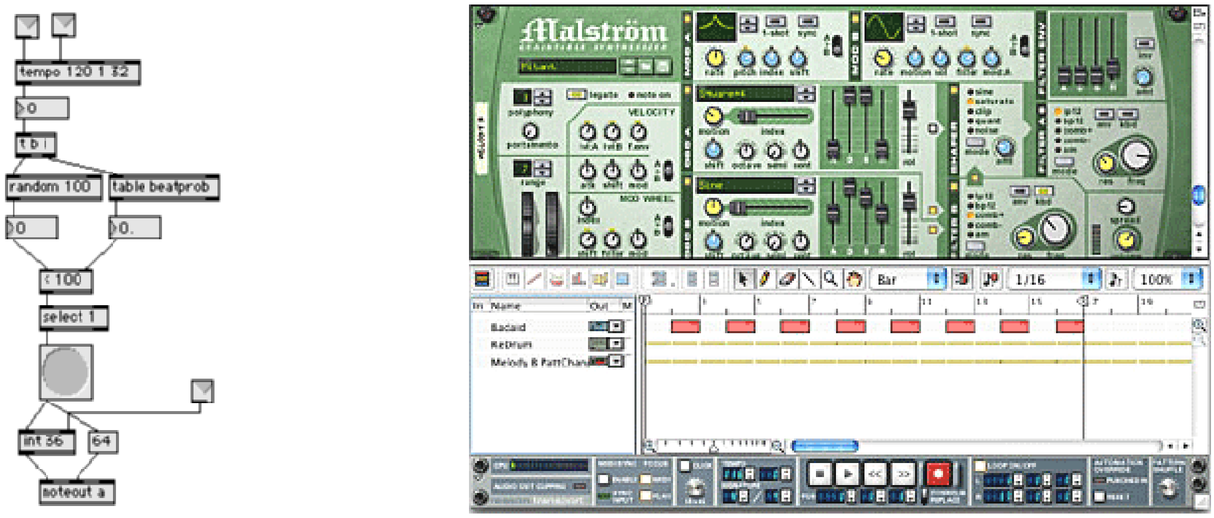

Figure 1. *(Left) MaxMSP patch example for the Aquarium Sonification system. (Right) Example Reason setup.*

that includes various types of sound generators which can use the MIDI data to create sounds from digital synthesizers or sampled audio. Max is powerful enough to process several different lists of data at a time. In our case, this gives us the ability to process three dimensions of coordinate data for many fish in the tank at a time. Along with pitch, timbre, and various types of distortion, Reason can also control the parameters of each generator with the same functionality as an analog mixer. A screenshot of one of Reason's synthesizers that generates digital sound is shown on the right side of Figure 1. The combination of Max and Reason can take real time data and convert it into meaningful sound as well as trigger narratives during certain events. Although we used sample data in the form of text files for our initial input, Max can take input in the form of streaming data from an external source. This allows us to make use of fish tracking hardware that we will use as input further into the project. Finally, for demonstration purposes, we have used the 3D animation program Maya to create virtual fish as a way to add a visual interface to the project (mostly for demonstration to sighted listeners). Users can see how the movements of fish in an aquarium will drive the sounds or music being created, and hear the result through headphones.

2.1. Soundscape Implementation Overview

Since we have such powerful software at our disposal, we have a multitude of musical attributes that can be mapped to a fish's movements or physical characteristics. We first take the 3D coordinate data from the path of each fish and process it into a format that can easily create a MIDI pitch or volume command. For example, if the coordinate data were between –50 and +50, the numbers would be scaled between 0 and 127, which are standard values in the structure of a MIDI note. After formatting the coordinate positions into usable data, several other patches were developed to determine direction, speed, and activity level of the fish. Other attributes of the fish such as size and color are recorded prior to gathering movement data. We are systematically exploring mappings of physical data values to sound parameters in order to determine what works best.

2.2. Mappings

To proceed in a systematic manner, we started began by listing the musical and sonification parameters that could easily be controlled in our system. We then listed the possible activities and attributes fish could display in an aquarium. Most of the mappings we chose are one-to-one, but some qualities, such as timbre and instrumentation, slightly overlap. Figure 2 shows possibilities for mappings from the fish and aquarium to the auditory domain. For each implementation, a logical combination of 'X' elements was chosen. Each element is controlled by different parts of our software. The instrumentation, intensity, narratives, and channel are most easily implemented by manipulating sliders, knobs, or samples in Reason. Pitch, rhythmic stability, and melodic stability are implemented in Max, while the other musical attributes can be determined by either program. In addition to choosing a mapping, we also considered how an attribute or activity would be mapped to each sound or musical aspect. This includes the notion of mapping polarity [7] and whether the mapping function is linear or exponential, such as when mapping distance onto loudness. Narratives (recorded speech segments) may have to be triggered on an event driven basis, such as when a particular fish approaches the front of the tank. One of the aesthetical choices we can make is whether to create sound in terms of music, information, or sound art. The ultimate decisions will have to be made in consultation with the ILE facilities themselves.

Fish	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
swim speed	X	X	X	X			X		X		X			
swim direction		X		X							X			X
swim accel.	X	X	X	X			X				X			
tank location	X	X				X	X							X
feeding			X	X		X			X					
interaction			X	X		X					X			
liveliness			X	X			X		X		X			
size	X	X			X		X			X		X	X	
color	X	X			X									
shape		X			X									
reflectiveness		X			X									
grouping		X		X	X	X						X	X	

Figure 2. *Mapping possibilities in the Aquarium Sonification.*

Fish	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
swim speed														
swim direction														X
swim accel.														
tank location		X					X							X
feeding														
interaction														
liveliness							X							
size		X			X		X					X	X	
color		X			X									
shape		X			X									
reflectiveness														
grouping												X	X	

Figure 3. *Mapping choices in the First Soundscape*

Fish	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
swim speed				X										
swim direction														X
swim accel.														
tank location		X					X							X
feeding														
interaction														
liveliness														
size	X	X			X									
color	X	X			X									
shape		X			X									
reflectiveness		X			X									
grouping														

Figure 4. *Mapping choices in the Second Soundscape*

2.3. First Soundscape Implementation

In the first implementation of the sonification (see Figure 3), audio parameters were controlled in real-time based solely on the particular fish locations. The manipulation of these parameters attempted to give a listener a "real-world" sense of location using spatialization cues.

A MIDI file containing a rendition of Johann Strauss's "Blue Danube" was read into Reason, and using various samplers, channels were mapped to appropriate instruments. Then, each fish was mapped to a particular instrument track. We used three fish in our implementation, each mapped to either a piano, a violin, or a clarinet.

The Cartesian coordinates of each fish were then used to control overall amplitude of each track, left-right pan, and spectral shaping (via equalizer control). The distance of the fish from the front of the aquarium was mapped to the amplitude level control for a fish's sound track. Through this mapping, a fish's sound became louder as the fish moved closer to the viewing window and quieter as it retreated. This mapping seemed intuitive, as (sighted) visitors would likely pay most attention to nearer fish. Next, the left-right location of the fish was mapped to stereo pan of each track. Again, this mapping was intuitive; as a fish moved from the left to right, its corresponding music moved from the left to right audio channel. Finally, the vertical location in the tank (z) was mapped to spectral shape of each fish's audio track. So, as a fish moved near the top of the tank, a highpass filter was increasingly applied (via Reason's EQ), causing a brighter tone. In this way, bottom-feeder fish would have a darker, bassy (no pun intended) tone.

2.4. Second Soundscape Implementation

The second implementation attempted to move away from pre-composed music, and allow the fish a way to generate their own music through their behavior. Because of this, it was necessary to explore higher-level, more abstract musical parameters (see Figure 4). This particular implementation focused on rhythmic stability.

We consider rhythmic stability to be a musical deviation from a "click track" rhythm. For instance, looking at typical 4/4 rhythms, an ideally stable rhythm by this definition would be beats on every quarter of the measure. This can be more easily thought of as the "foot-tapping" rhythm. To control deviations from this stable rhythm, probability tables were used that defined the likelihood of an onset at each beat quantization level (in our case, 16th of a measure). That is, a stable rhythm would have very high probabilities of onset on the quarter-measures and relatively low probabilities on the 16th-measures. So, simply by increasing the relative probabilities of these "off-beats", a more unstable rhythm emerges.

This probability table was set to an appropriate stability range and made controllable by a "stability parameter". This parameter could then be driven by a number of physical attributes. In this particular implementation, stability was controlled by the speed of the each fish. A slow moving fish would have a relatively consistent and stable rhythm; as a fish moved faster in the tank, its rhythm became more unstable.

The actual notes played by each fish in this implementation are notes from major triads played randomly according to the rhythm set as described. Each fish not only corresponded to different timbres (as set by the synthesizer used in Reason), but different triads. We used three fish with C, F, and G triads respectively, corresponding to the musically significant I-IV-V progression. This allowed for all of the fish to be generally consonant with each other, while still remaining distinct.

The same mixer controls used in the first implementation were used again to add further spatialization cues.

2.5. Third Soundscape Implementation (In Progress)

The third implementation we are currently developing continues exploring the control of higher-level musical aspects as before, however now in the realm of pitch and melody. Using similar methods, we are looking at the effect of controlling melodic stability of a particular phrase. We are using Markov models to set the probabilities that a certain pitch will follow another. A set melodic phrase's note sequence can be generated by setting these transition probabilities, and this phrase can be made unstable by increasing the likelihood of deviating from the base melody. Data obtained from studies in key profiles and pitch classes [8, 9] are currently being used to set appropriate melodic stability ranges.

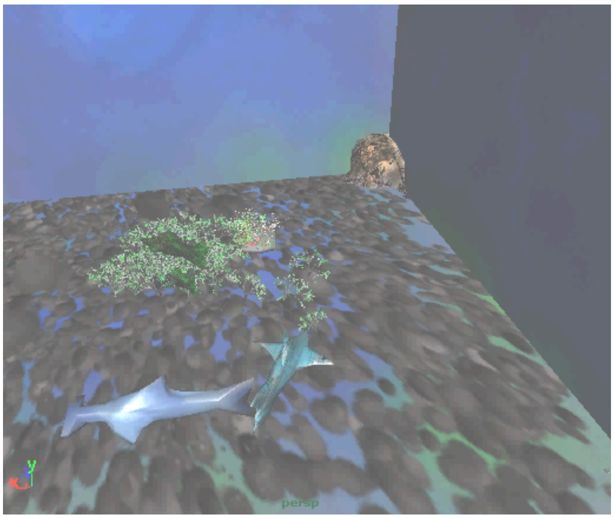

Figure 5. *Visual simulation of aquarium, showing fish of different sizes and movement behaviors.*

2.6. Visual Aquarium Simulations

To facilitate more rapid development and demonstration of each implementation, we have created a virtual 3D fish tank using polygon surfaces in Maya. Each fish is created starting with a basic polygon cube or sphere, which is then split and stretched until the shape of the desired fish emerges. Figure 5 shows several fish in our virtual aquarium. Afterwards, the fish are animated along drawn curves at arbitrary speeds. These curves are also pulled and stretched in different dimensions to show possible fish movement throughout the whole tank. The data from each curve is then exported into Max to be processed. This method lets us create any activity, movement, shape or color we desire to allow users to see what would be happening in an actual tank, while listening to the produced sound at the same time. Although the simulations are great in terms of getting the general picture, we must also consider what would actually be happening in front of a large pane of glass. A person will be looking at a large aquatic scene instead of a computer screen. We plan to record data on how visitors observe aquaria in the near future.

3. EVALUATION AND FUTURE IMPLEMENTATIONS

Our first several implementations have met with success. Each subsequent choice of mappings creates new sound and music that better represents each fish in our virtual tank. Viewers and listeners should be able to get an idea of what sounds correspond to what fish as well as what activity is going on in the water. This technology can be converted to a static setup with the use of fish tracking hardware.

In upcoming implementations, we will continue to explore other mappings that may be applicable to this project. Aside from basic one-to-one timbral mappings (such as instrumentation and tone to physical fish attributes), we will continue to investigate the use of high-level musical control and synthesis techniques. More psychological and cognitive relations between the visual aquarium stimulus and a representative sonification will also be examined, such as mood and emotional intensity.

One area yet to be explored is interaction among the fish. This is clearly one of the more interesting occurrences to observe at an aquarium and an obvious choice for further sonification focus.

4. CONCLUDING REMARKS

It is the dynamic nature of aquaria and zoo exhibits that draws visitors. To truly provide an accessible experience in such facilities, we must determine effective means to convey not only what is in the exhibit, but also where it is, and what it is doing. Auditory displays can provide a rich and informative channel for this information, and will enhance the experience for all visitors, in the truest spirit of Universal Design.

5. POSTER PRESENTATION AT ICAD2006

Our main poster will present the overview and background materials that motivate the project, as well as descriptions of at least three implementations. We plan to have several laptops set up so that visitors can watch the fish swimming around the aquarium, and at the same time listen to the corresponding audio via headphones. These three “stations” will allow visitors to compare the soundscapes directly. We will also have the Max/MSP + Reason system running for the curious sound designers to play with. Sample CDs or DVDs of the software and of the resulting soundscapes will also be available for visitors to take with them.

6. REFERENCES

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