

MUSICAL SOUNDSCAPES FOR AN ACCESSIBLE AQUARIUM: BRINGING DYNAMIC EXHIBITS TO THE VISUALLY IMPAIRED

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ABSTRACT

In an effort to make an aquarium, zoo, or other dynamic “informal learning environment” more accessible to the visually impaired, we track the fish (and other creatures) with computer vision, then use the movement data to create meaningful and aesthetic music. Here we present four new classes of “soundscapes”, which demonstrate a range of data-to-music mapping approaches. This follows on the initial prototype work, discussed previously. A systematic exploration of the possible composition and design space is leading to music that communicates the dynamic aspects of the exhibit (e.g., how many fish, what kinds, where they are, what they are doing), as well as conveying the emotional content (e.g., amazement and wonder at the massive whale shark gliding by). Informal evaluations have been very successful; formal evaluations are ongoing.

1. INTRODUCTION

Among the common goals of informal learning environments (ILEs), including museums, science centers, zoos and aquaria, are the entertainment and education 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 accommodating an increasingly diverse visitor population with varying physical and sensory needs. Although architectural suggestions such as the Americans with Disabilities Act Accessibility Guidelines (ADAAG) [1] have improved facility access, these requirements are primarily intended to facilitate physical 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]. Unfortunately, there are no solid

guidelines for how to enhance accessibility of dynamic ILEs for visually impaired visitors.

In response to the lack of guidance that would enable ILEs to provide more accessible exhibits and interpretation, we at Georgia Tech have begun to study methods of using sound—both musical and non-musical—to enhance the interpretations of exhibits, thereby providing greater access to these exhibits. The work of our “Accessible Aquarium Project” applies equally to aquaria, zoos, natural science museums, and other dynamic ILEs [5]. The ultimate goal is to communicate to the (visually impaired) visitor what is happening in a dynamic exhibit, as well as the “feeling” or mood that a sighted visitor might experience. For example, we would want to communicate how many fish are visible, where and how they are moving, but also share the impressiveness and “ooh, ahhh” feeling one gets as a huge whale shark glides by. This enables the visually impaired visitor to experience an exhibit on both cognitive and emotional levels, and it also provides a shared experience so that sighted and visually impaired visitors can discuss their understanding and impressions of the exhibit later. A key element in this is the creation of music that conveys both information and mood.

Before any music or other sounds can be created, the first technical stage of the work is to actually track the fish, sharks, lions, molecules, or whatever is moving in the exhibit. This is being tackled in our project with a mixture of computer vision and electronic tracking devices. For the present purposes, suffice it to say that the tracking system produces multiple streams of 2- and 3-dimensional movement tracks, sampled several times per second. The set of streams (typically one movement stream per fish, in the case of the aquarium) can then be used to drive a dynamic multimodal display. The basic system concept has been reported before, with a focus on the prototype system and initial musical outputs [5]. The present paper discusses the ongoing progress in the project, which now includes fully automated tracking, a client-server architecture for distributing the tracking streams, and a sophisticated music- and sound-generation capability. The present paper extends upon the earlier work by introducing real videos (including more than one type of exhibit), automated tracking, area-based global interpretation of displays and new approaches to composing musical soundscapes.

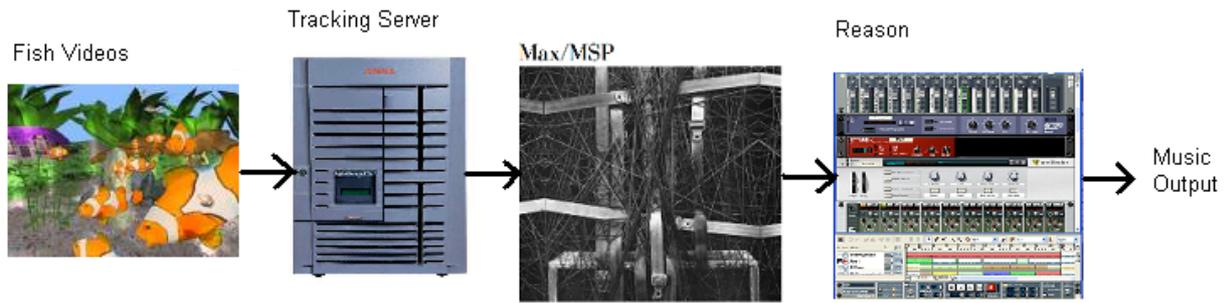


Figure 1. Schematic of the music generation process, starting with camera tracking of fish, and leading to Max/MSP.

1.1. Auditory Displays in Museums and Aquaria

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 [6]. From the basic technologies like audio labels and tape recordings, to the more innovative approaches of using cell phones, MP3s, and Podcasting [7], 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. 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, exhibit-driven music, and sonification, shown to be useful in many domains, have been almost completely ignored. To our knowledge, the topic of music generated on the fly from exhibit dynamics has apparently not been discussed in the museum context, and certainly not as an assistive technology (except, of course, [5]).

1.2. Biologically Inspired Music

This project attempts to interpret biological entities and phenomena intuitively and aesthetically. Variations in size, species, movements and behavior are mapped to music attributes to make them as easily interpretable as possible. The aim of this research is to convey all the aforementioned information naturally so that the listener makes an automatic association between the music he or she hears and (what would otherwise be seen in) the visual display. Listeners have mental models that correlate certain properties of music with specific behaviors and moods [e.g., 8-10]. For example, high-pitched sounds may be associated with smaller sizes whereas low-pitched sounds may be associated with larger sizes. Likewise, in our experience, if given a choice between a trumpet and a violin most persons will

match the former to a whale and the latter to a goldfish. Similarly, fast paced music is associated with quicker movements whereas music with a low tempo is associated with slow heavy motion. We have utilized these kinds of mappings to represent the movement of animals (fish, ants, and others) with music. Stereo panning has naturally been used to indicate direction of motion along the left-to-right axis [5].

In addition to the simple location and movement directions, we have also begun to map some more complex, higher-level behaviors to music parameters. The soundscapes discussed here reflect some basic behaviors such as entry to, and exit from, designated exhibit areas. Considerable work is ongoing in that vein.

1.3. Music from Dynamics

While apparently not deployed as interpretation aids in museum and aquarium exhibits, there are certainly many examples of on-the-fly dynamics being incorporated into music performances. In some cases the musicians or audience move [e.g., 11]. In other cases, there is some other moving creature(s) serving as an external source of inspiration. Of particular relevance to the present project, there are some recent examples of music being generated directly (and automatically) from creature movement dynamics. In one well-known project, hamster movements were used to drive MIDI compositions [12]. In another well-known project, movements of fish in a lake (monitored using hydrophones and embedded biotags) were used to drive music compositions and visuals [13]. Those projects used different tracking methods, and ultimately had different goals than the current effort. Nevertheless, they show that interesting and engaging music can be derived from the base of creature movements. Our goal is to extend and explore this design space in a somewhat systematic manner, in order to go beyond performance, and into the realm of communication and exhibit interpretation, especially for visitors unable to interact visually with the exhibit.

2. SONIFICATION SYSTEM DESIGN

We have taken a flexible data-to-sound mapping approach that will accommodate a range of data types,

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Creature Feature														
Speed	X	X	X	X			X		X		X			
Direction		X		X							X			X
Acceleration	X	X	X	X			X				X			
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. Example analytic type of mapping ensemble, when specific fish movement is mapped to sound attributes

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Quadrant Attribute														
Average Speed	X	X	X	X			X		X		X	X		
Average Direction											X	X	X	X
Right/Left					X	X		X						
Upper/Lower	X	X												
Feeding					X			X	X					
Interaction					X			X						
Grouping	X	X		X			X		X	X				X

Figure 3. Example holistic type of mapping ensemble, in which more aggregate types of data are used to generate the soundscape.

exhibit events, and resulting auditory outputs. The engine for our sonification is built on Max/MSP. 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 a schematic of the tracking system providing input to a Max patch that interacts with Reason or other similar software. 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.

Our system can use live tracking data, however for the purposes of development we have recorded several sample videos and their associated movement data streams. We use those recorded data sets to compose the music and other soundscape components, before turning on the live feed again. We have video from a range of biological species, including fish, birds, primates, and ants. It is important to be able to compare the different biological systems in terms of their inherent movement and behaviors, and in terms of the implications for developing an auditory display that meets our functional

and aesthetic goals. We also note that in the current system a visitor can listen to the audio via wireless stereo headphones.

2.1. Soundscape Implementation Overview

Before we begin to create a soundscape, the movement data for each fish are processed 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 Max patches are employed to determine direction, speed, and activity level of the fish. Additional attributes of the fish that we get directly from the visual tracking system, or from system configuration settings, such as size and color, are also collected and recorded prior to gathering movement data.

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Creature Feature														
Speed			X											
Direction		X												X
Acceleration			X											
Location		X												X
Feeding														
Interaction														
Liveliness			X											
Size	X				X							X		
Color	X	X			X									
Shape		X			X							X		
Reflectiveness					X									
Grouping														

Figure 4. Mapping ensemble for Soundscape 1.

2.2. Soundscapes Covered In Previous Work

The soundscapes presented previously [5] used a 3D aquarium model generated in Maya to produce artificial fish, following artificial movement tracks. In the first soundscape generated with that prototype system, each track was mapped to a different MIDI instrument playing a separate part in the ‘Blue Danube’ waltz [5]. Each instrument in the music corresponded to a different fish. As a given fish moved closer or farther, or left or right, the instrument was made louder or softer, or panned left or right in the stereo channels. This was a very basic, but also very direct and intuitive mapping that was very well received by listeners.

The next soundscape generated music algorithmically through the movements of the fish, rather than using a pre-decided melody. Each fish drove a different instrument resulting in a biologically inspired symphony. Specific notes were generated using a stochastic process, within a musical framework. Thus, the music was unique every time, but sounded musically pleasant as well. Fish speed controlled, for example, the relative probabilities of transitioning from one given note to another. The present work follows more in line with this second approach, namely generative synthesis, rather than simply adjusting MIDI channel parameters.

2.3. Mappings

There are clearly a multitude of musical attributes that can be mapped to a fish’s movements or physical characteristics. In recognition of this, we attempt to take a systematic approach to exploring the large space of design/compositional possibilities, rather than randomly trying different things (although there is still plenty of experimentation involved).

Another distinction in the music mapping design is whether the data from a specific fish are used to generate a particular sound component, or whether some more

holistic or aggregate data are used. That is, as a particular fish moves from left to right in the tank, a trumpet sound could move from left to right in the auditory space. This one fish-to-one instrument mapping approach, which we call *analytic* mapping, was the main focus of previous work [5]. On the other hand, more complex behaviors, data from several fish combined, or data based on a geographic region of the tank, rather than a specific fish, can also be used to drive a soundscape. We call this *holistic* mapping, and examples include slightly more complex behaviors such as a fish entering or exiting a voxel, or the density of fish within a given voxel at a given time. This holistic kind of mapping is new to the present paper.

Here we carry on the systematic approach from [5] in which we produce a table of many of the musical and sonification parameters that can be controlled in the system, crossed with the many possible activities and attributes fish could display in an aquarium. See Figure 2 for an example. Then, for each implementation, a logical combination of behavior-to-sound mappings (the set of ‘Xs’ in the figure), called a mapping *ensemble*, is chosen and implemented. Each element in the ensemble is controlled by different parts of our software, and there is certainly a considerable variety of ways a particular mapping can be implemented. Thus, even with this systematic approach, there is still great flexibility available, and creativity required. 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 [8-10] and whether the mapping function is linear or exponential, such as when mapping distance onto loudness.

For holistic kinds of mappings we followed a similar procedure (see Figure 3 for an example). We listed the possible variations in screen areas such as creature density, movement and average speed. Narratives (recorded speech segments) were also used in holistic mapping. The narratives are triggered by creatures entering or exiting specific screen areas.

Beyond the fundamental decisions regarding mappings, we also had to be careful to address the aesthetic quality of the music. The musical output has to serve the dual purposes of conveying information and at the same time providing the audience with a pleasing auditory experience. We have tried to produce an ideal combination but the ultimate decisions regarding the finer points of the display will have to be made by the consumers of the ILEs themselves.

3. SOUNDSCAPE 1

Overview: Computer generated fish, each mapped to a separate musical instrument.

The aim of this soundscape implementation was to find a balance between the informative and musical functions of our system. Since the primary goal of this project is make ILEs more accessible to visually impaired visitors, instead of investigating new styles of music, we decided to apply well-known musical styles to the fish video. We used a classical music style for this soundscape implementation, specifically the chord progression from Pachelbel's Canon: I-V-vi-iii-IV-I-IV-V. This chord progression is still being used by many modern musicians and is very familiar to many listeners.

In Soundscape 1, the chord changes from measure to measure according to the preset tempo and progression. The behaviors of fish are mapped according to Figure 4. For example, the speed of fish is mapped into the density of notes (how often it plays), so that as the fish moves faster, more notes will be played according to the chord progression. The sample Max/MSP implementation is shown in Figure 5.

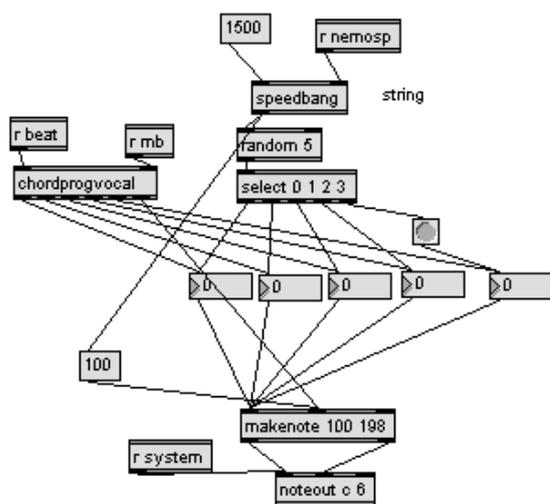


Figure 5. Max/MSP implementation for speed mapping.

Next, the generated note is passed on to Mixer in Reason in order to be filtered and mixed down according to the direction of its movement. Movement in the x-axis (audience left or right) is expressed by adjusting the left-and-right pan control with Mixer 14:2 in Reason. Movement in the y-axis (depth in the tank) is expressed by ECF-42 Envelope Control Filter to control the timbre by changing the resonance frequency so that as a fish goes up in the tank, the corresponding instrument will sound sharper and brighter and as it goes down, it will sound duller and thicker.

Another interesting feature of the system is its controllability of the speed sensitivity threshold. The basic idea is to set different speed sensitivity threshold values for each fish so that a fish with higher threshold will be more sensitive to its speed. This enables the higher-threshold fish to play notes more often than a lower-threshold fish. A higher speed sensitivity threshold is assigned to a smaller fish and a lower one to a larger fish. The assumption is that a smaller fish requires more movements such as flexing and twisting its body in order to move with a given speed while a larger fish might need one big easy flex for the same. With this speed sensitivity threshold application, we are able to map not only the speed of fish but also its liveliness.

4. SOUNDSCAPES 2a and 2b

Overview: Real ant movements mapped to separate musical instruments, with Rock and Jazz variations.

Since the movements of the tracked entities are mostly unpredictable, our system generates more upbeats than downbeats. This inspired us to compose a jazz piece wherein upbeats are more common than in other musical pieces. Instead of tracking fish, we tracked (real) ants to demonstrate that our system can be applied to a variety of moving objects, including real creatures other than fish. To compose a jazz piece, commonly used jazz instruments such as the trumpet, piano, organ, ride cymbal, etc. were assigned to each ant. We used chord progression repeating by CM7 – FM7 – Em – Am in the scale of C major.

One of the difficulties for mapping ants to a musical piece is that there are no obvious characteristics that can enable us to distinguish one ant from another. It is not possible to map the size, color, shape and other physical characteristics of ants, as was done with the fish. However the ants are livelier and faster than fish, in general, and thus “make” more interesting jazz music. The technical approach used was the same as with the fish, however a slightly different sound mapping is used, as illustrated in Figure 6.

5. SOUNDSCAPE 3

Overview: Mapping of screen region activity to music, using ant videos.

Our initial soundscapes used a one-to-one fish to instrument mapping. The variations in music indicated a variation in the fish movements. The audience could follow the fish movements by listening to the changes in

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Creature Feature														
Speed			X											
Direction		X												X
Acceleration			X											
Location		X												X
Feeding														
Interaction														
Liveliness			X											
Size														
Color														
Shape														
Reflectiveness														
Grouping														

Figure 6. Mapping ensemble used in Soundscape 4 (similar to Soundscape 1).

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Quadrant Attribute														
Average Speed			X											
Average Direction														
Right/Left					X									X
Upper/Lower	X													
Feeding														
Interaction					X									
Grouping							X							

Figure 7. Mapping ensemble for Soundscape 3 with ants moving around the four quadrants.

the musical track. A similar approach was followed in the ants Soundscapes 2A and 2B, discussed above.

However, when the number of tracked creatures in the field of view increases (e.g., simultaneously tracking 20 fish within a school, which our system can easily handle), it becomes difficult for a listener to differentiate between the musical instruments. If there are more than 5-6 fish (or ants, etc.) in view at a time then the listener finds it difficult to visualize the individual movements of each creature. This is especially true when there is not the strong melodic line of a pre-composed piece. The music produced can also lose some of its aesthetic value when numerous tracks are superimposed. All of this is not unlike the experience of a sighted visitor trying to watch a growing number of fish simultaneously, so the fact that it is hard to follow the many fish auditorily is actually informative, and leads to a similar experience for sighted and visually impaired visitors.

However, as part of our explorations, we looked at alternative approaches, in order to determine ways to convey more global information. To represent a high density of tracked items, we can use some holistic approaches to music mapping (see Figure 7). Instead of

musically encoding the behavior of each creature, in this case we musically encoded the different areas of the screen. For the purposes of Soundscape 3 the screen area was divided into four parts. The left side and right sides of the screen were mapped to a different instrument each. Different pitches represented the upper and lower quadrants of each side of the screen. At all times four MIDI tracks play concurrently, based on how much activity there is in the various regions. A function to compute quadrant density was written in Max. Quadrant density refers to the number of tracked items present in a given quadrant at a given time. The loudness of the MIDI track corresponding to each quadrant varied in direct proportion to the number of creatures (in this case, ants) present in that quadrant. The absence of any fish or ants in a quadrant was represented by the quadrant track playing at zero volume. The left and right hand quadrants were represented by panning left and panning right respectively.

	pitch	timbre	tempo	rhythmic stability	instrumentation	narrative	intensity	voice gender	mood	tonality	melodic stability	melody	accomp.	stereo channel
Creature Feature														
Speed			X											
Direction		X												X
Acceleration			X											
Location		X				X	X							X
Feeding														
Interaction														
Liveliness														
Size	X				X			X						
Color	X	X			X			X						
Shape		X			X			X						
Reflectiveness		X			X									
Grouping						X								

Figure 8. Mapping ensemble for Soundscape 4.

6. SOUNDSCAPE 4

Overview: Real fish mapped to separate instruments, along with voice narrations.

Since our system now supports live video, as well as recorded video from real dynamic exhibits, we felt it important to revisit some of the earliest soundscapes that we produced, as described in [5]. Those were based on artificial creatures rendered in a 3D drawing program. While they served the purpose at the time, it was important to investigate whether the broader range of possible behaviors, along with a greater degree of unpredictability that come from real animal movement, necessitated a different sonification approach. Thus, returning to the fish domain, Soundscape 4 here is an extension of the second soundscape from [5], in that the same sonification approach has been applied to a video of real fish (see Figure 8).

In addition to investigating the effect of a natural movement source, this soundscape also adds the use of voice narrations that are activated upon the fish entering the central area of the screen. Each fish has a MIDI track associated with it. When the particular fish enters the center of the screen a pre-recorded (.WAV) sound file is played that identifies the particular fish. Thus, this soundscape incorporates both analytic and holistic methods, combining and building on the work of previous soundscapes. It was important to consider how these two types of stochastic processes interact.

We should point out that there is a strong rationale behind the introduction of narrations into the musical display. Though we have tried to make the musical representation of each fish correlated with the fish appearance (e.g., the large shark is represented by a lower pitched sound while the smaller fish are represented by higher pitched sounds), a listener may not be able to learn to pair the fish movements with the identity of the fish unless explicitly trained. To enable on-the-fly training, so no prior experience is required of

a visitor, the position-triggered voice announcements help the audience correlate the musical tracks with the fish. The algorithm triggering the narration files ensures that the voice announcement for a fish is presented only once within a time window, which prevents the system from continually saying the fish name. The algorithm also ensures that no two narration files are triggered concurrently. This is of great importance since more than one fish can be present in the central area of the viewing window.

7. EVALUATION AND FUTURE DIRECTIONS

With our powerful tracking and soundscape generation system now in place, we have begun to systematically explore the design and composition space that has been made available. It is important to evaluate the effectiveness of these initial musical experiments, and consider how to extend this novel approach to making ILEs more accessible. The metrics for success include both functional and aesthetic assessments. That is, the music and narrations need to provide access to the goings-on of the dynamic exhibit, while also sounding at least “acceptable,” and preferably “great,” to the visitors.

Our first several implementations have met with success in both aspects. While we are only now entering the next phase in the project where we conduct empirical evaluations of the soundscapes, we have already informally presented our examples to approximately 40 sighted and 20 visually impaired listeners. All of the soundscapes have been rated “acceptable” aesthetically, with expected individual variability in terms of preferences. Some listeners prefer the jazz version of the ants soundscape; some prefer the rock version. The simpler, analytic types of soundscapes are generally easier to follow, but many listeners report they sound too simple. On the other hand, listeners report that some of the more complex soundscapes, with many creatures, can be hard to mentally track. However, the overall dynamics, such as how many creatures are present, in

what parts of the exhibit, and how fast they are moving, is generally comprehensible to listeners. We note that some of the more sophisticated mappings, such as mapping movement speed onto pitch or tempo irregularity (e.g., Soundscape 4) were more cognitively engaging (and ultimately more interesting) to listeners than were the simple MIDI approaches. While this is not surprising, it does suggest that different audiences (e.g., school children versus symphony season ticket holders) would prefer, and possibly require, different mapping approaches.

Moving forward, we plan to implement artificial intelligence components to the tracking system, in order to automatically extract actual complex behaviors such as feeding, creature interactions, and “mood” attributes such as the level of tension or excitement in the exhibit. We can then investigate how to use sounds to convey these more psychological and cognitive attributes.

8. CONCLUDING REMARKS

The dynamic nature of aquaria and zoo exhibits are a big reason people visit, and then return repeatedly. To provide a truly 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 involving music, spoken narrations, and other non-speech components, 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. We are building on both music theory and participatory design, to ensure a fully functional, educational, effective, and entertaining experience.

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