Education Through Music Technology

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***Abstract*—Our music technology research group has developed a series of formal and informal education programs that motivate both music and STEM (science, technology, engineering, and math) education through music and audio technology. The first program, called iNotes, is a collaboration with the Philadelphia Orchestra. iNotes is a system which tracks the audio of a live orchestral performance and uses acoustic features to align the performance to the musical score. We informally educate users by presenting real-time contextual information about the performance to a user's mobile device, giving them a greater understanding of the piece as it's performed. Our second, more formal education program, the Summer Music Technology program (SMT), is a week long summer camp that introduces the engineering, science, and mathematics behind modern music technology. Each lesson emphasizes signal processing concepts, tools, and methods through hands-on activities without requiring any background knowledge. Lastly, we are currently developing an event called "The Science of Music", where a live performance will be accompanied by projected visuals and a mobile application that updates in real-time along with the performance, conveying simple concepts relating music to its underlying technology.**

I. Introduction

When a person enters a museum, they often have the option to use an automated, handheld personal tour guide, usually in the form of an audio recording that explains facts about individual exhibits. This enables a visitor to better understand and appreciate exhibits and provides curators with the ability to communicate with audiences on a personal level. Similarly, many performing arts organizations are actively experimenting with interactive, educational activities. Someone who attends an orchestral performance may find it difficult to follow and understand a concert program and would benefit from some additional guidance. Our system, the *Philadelphia Orchestra iNotes*, provides an automated personal guide that presents time-relevant annotations and contextual information on a handheld device. Using this system, concert attendees will be able to learn about the music as it is performed and gain a deeper understanding of each piece. In addition, because it is viewed on a personal level, it is unobtrusive to those audience members who do not wish to use the system. The system is able to automatically determine the current location within a live performance, in terms of music measure number, without the need for a human score follower to trigger events.

Because of the iNotes system and our previous experiences with educational outreach geared toward a general, public audience, the MET-lab was also asked to develop an event, "The Science of Music", for the Philadelphia Science Festival. The Philadelphia Science Festival is held in April and attempts to bring educational and cultural organizations together to promote science throughout out the city of Philadelphia.

Additionally, we have developed a more formal education program, the Summer Music Technology program (SMT). Over the past five years, we have developed a series of lessons designed to introduce high school students to the engineering, science, and mathematics behind modern music technology. Each lesson emphasizes signal processing concepts, tools, and methods through hands-on activities that require minimal prerequisite knowledge. The activities, which were developed by signal processing engineers with musical backgrounds, focus on different aspects of music technology and have learning objectives that students should understand after completion. The inquiry-based program strives to maximize time spent engaged in activities and minimize lectures. Additionally, the activities are designed to be portable and useful to other instructors, either individually or as a unit, and are available online for any interested instructors and organizations.

II. Informal Education Efforts

A. Philadelphia Orchestra iNotes Collaboration

The iNotes project is a collaboration between the MET-lab and the Philadelphia Orchestra to help engage an audience and teach them about classical music. The overall system design of the *Philadelphia Orchestra iNotes* is outlined in Figure 1.

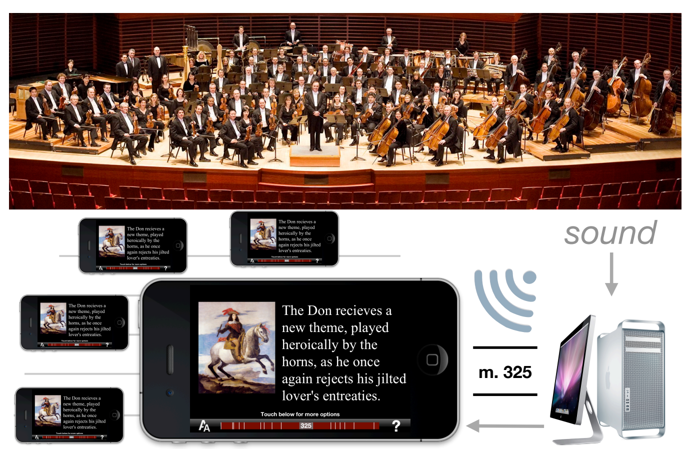


Fig. 1: iNotes system

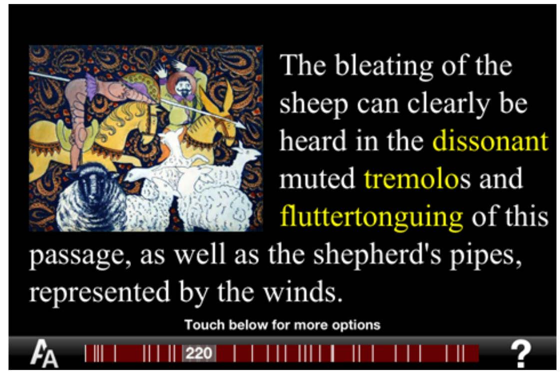
A live orchestral performance remains the focus of each event. As a performance takes place, the live audio is streamed to a computer that attempts to find the current position of the orchestra within a piece. This is accomplished by using acoustic features extracted from the live music stream and aligning them with those extracted from a previous recording of the same piece. This effectively determines the position in the live performance as it relates to a corresponding position in a reference. As the temporal locations of measures and other events in the reference are already known, the system is able to determine the position of the live performance (e.g., "measure 325"). The position is then sent to the handheld devices, which display information relevant to the current location within the piece.

1) Audio Alignment: Prior to a live performance, a reference recording for each programmed piece is manually time-stamped (annotated with time values corresponding to important measure numbers). The system effectively follows a performance by aligning the live music with the previously annotated reference recording. This alignment is performed using an acoustic feature known as *chroma*, which relate to the current notes being played [1]. During the concert, the system calculates the chroma features of the live audio from the orchestra, and by using *dynamic time warping* (DTW), it aligns them with the chroma features from the previously annotated recording [2]. This alignment can be used to infer the measure position of the live performance. When the tracking application determines the equivalent position of the live audio as related to the reference recording, it looks up the corresponding measure number, which is then broadcast to the handheld client devices in the audience to trigger the display of relevant content.

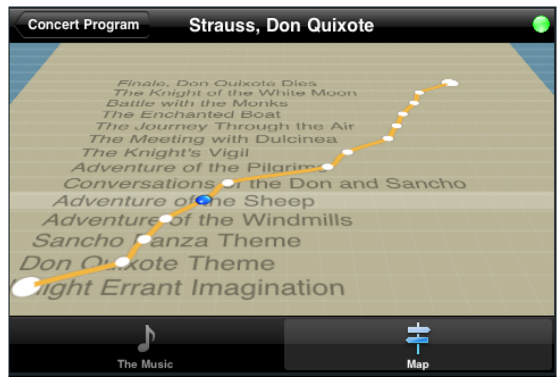
2) The Application: Our primary interface uses a slideshow-style display (Figure 2a). As the music progresses, pages of information containing text and supporting images are displayed. One can allow the system to update pages on its own, guiding one through a performance, or page through the information at one's leisure. The current position within the piece is visible at all times via the updating timeline at the bottom of the slide. Tick marks within the timeline show the positions of annotations. The application is designed to easily accommodate supplemental information such as musical vocabulary and definitions. In Figure 2a, the word "fluttertonguing" is a hyperlink to the glossary, offering a definition.

Annotations can also be presented as multiple tracks of information, each focusing on a different aspect of the music. In addition to the slide interface, we have also developed an interface that uses the metaphor of a "roadmap" for music. The beginning and end of each piece are depicted as starting and ending points on a map. One can glance down at our application's map view to obtain a sense of the current location within the overall structure of the piece: where it's been, and where it's heading. An example map, given in Figure 2b, shows the entrance of a new section.

3) Content Creation: Before each concert, the musicologists begin creating time-relevant performance notes linked to measure numbers or rehearsal markings in the music. Topics range from music theory concepts to a piece's historical significance, spanning anything the author feels may be helpful



(a) This is an example of the slide-style interface. Certain words on the slides, such as 'dissonant', 'tremolo,' and 'fluttertonguing' are highlighted and act as hyperlinks to a glossary of musical terms.



(b) Map-style interface

Fig. 2: Annotation content relating to measure number 220 of Don Quixote by Richard Strauss.

for an audience member to better understand a performance. These collaborations generate greater value than just the content created. In working closely with the annotators, we obtain feedback regarding our system from those who are most likely to incorporate it into their own education activities. We have integrated this feedback into our system to improve the presentation of the content the designers seek to convey.

B. Philadelphia Science Festival "Science of Music" Event

Recently, we have been designing a "Science of Music" performance event. This is motivated through both our experiences in mobile applications and real-time audio analysis from the orchestra project and our experiences in teaching STEM concepts through SMT. In designing a hybrid of the two, we plan to present a live performance enhanced by real time visuals that explain wavelength though string length, harmony through chroma and harmonic overlap in the spectrum, timbre though the overlap of spectra for each instrument, and hall acoustics though a sound field demonstration using microphones from each person's mobile device. The goal is to give the audience a better appreciation for the acoustics and music technology behind the performance.

III. Formal Education Efforts: SMT & GK-12

A. SMT Program

SMT has enrolled over 100 high school students and has recently completed its fifth session. The program serves to attract students from backgrounds underrepresented in engineering, math, and science who may not have previously considered further study in these fields. The curriculum has been revised each year with new material and includes significant contributions from graduate and undergraduate engineering students.

Each summer, a group of 20-30 students from the Philadelphia area is admitted into the program. The program consists of five six-hour days divided into four activity blocks. Eleven blocks are dedicated to structured activities where students participate in a hands-on lesson in a particular topic. The high school students fill out surveys after each activity, providing feedback on how interesting and difficult an activity was, as well as how much students feel they learned from it. An additional seven blocks are dedicated to individual student projects. These projects allow students to explore an area they find interesting in greater depth than any of the activities allow. This gives students the opportunity to experiment and come up with ideas of their own. At the end of the week, each student gives a short presentation on the results of his or her project.

Six of the activities were also implemented as part of the STEM Scholars Program hosted by one of the city's largest science museums. Its aim was to prepare underserved students for college and to increase matriculation into STEM fields. This allowed us to test our methods on a different subset of students who did not specifically seek out a music technology program. More information about this program can be found in [3].

B. Activity Development

The majority of software development for SMT is done using PureData (Pd), an open-source real-time programming environment for audio, video, and graphical processing initially developed by Miller Puckette (creator of the similar, commercially available Max/MSP application)[1]. We chose this software primarily because of its real-time audio processing capabilities, which enables interaction with audio signals and real-time feedback. Pd's graphical programming environment is also easier for students to comprehend without prior programming experience. Students can visualize the signal flow within a program by using "patches", shown in Figure 3. Because it is open-source and freely available, interested and motivated students can download it to their computers at home. This allows students to continue working on their projects overnight and even after conclusion of the camp.

C. Activities

1) Speaker Building: In the Speaker Building activity, students learn the physical principles behind speaker operation by building one out of household materials. The speaker is built by fastening a wire coil, which the students are asked to build, to a paper plate hung from a cardboard housing. The coil is then connected to an amplifier and, by holding a strong magnet close to the wire, the plate vibrates and produces sound. Through this process, students are taught about the basic functionality of a speaker and which factors effect its sound quality and performance.

[1]http://puredata.info

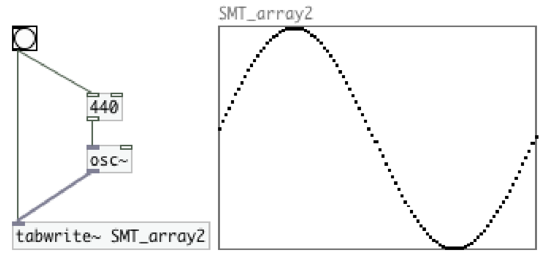


Fig. 3: Example of a simple PureData patch

2) Waves and Sounds: Waves and Sounds allows students to explore the nature of sound. A short introduction teaches students the basic principles of sound using real-world examples. Afterwards, they learn how basic periodic signals can be created and viewed using a function generator, oscilloscope, and the Pure Data application. Students are also exposed to the frequency limits of human hearing and the concept of harmonics (overtones).

3) Echo and Sound Design: Echo and Sound Design teaches students about the basics of echoes and digital sound design. The lesson begins by using GarageBand to experiment with shifting copies of a sound and listening to the echo-like result. They then move outside of the classroom and listen to a real-world echo to provide them with a sense of the echo's timing. Returning to the classroom, students use Pd to explore the echo simulation.

4) Musical Instrument Acoustics: Musical Instrument Acoustics is divided into two activities. The first activity uses PVC tubes to explore the concept of resonant frequencies and filtering. Speakers play sounds into the tubes, and the sound at the other end of the tube is recorded for comparison to the input. The second activity looks at different musical instruments and explores how they produce sound. Similarities and differences between the different families of instruments (e.g. strings, brass, woodwind) are also explored. The two parts of this activity can be split up and used individually.

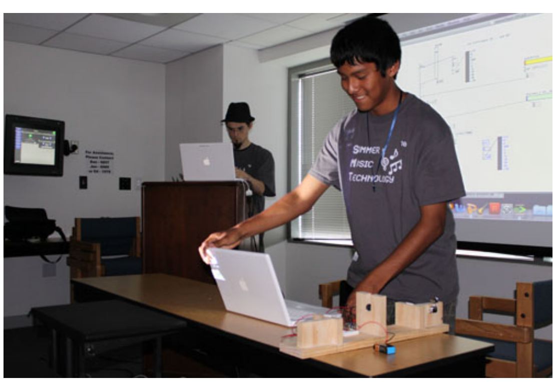
5) Musical Interfaces: The Musical Interfaces activity is another two-part activity. It explores the use of nontraditional interfaces and computer-based instruments in music. Five different interfaces are available and can be connected to a Pd patch. In the first part of the activity, students are given an interface and asked to experimentally determine how it controls sound generated from a computer. Controls on the interface are set up to change features such as volume, pitch, and harmonics. Each group presents their findings to the class and demonstrates how their particular device works. In the second half of the activity, students are asked to customize their own interface by manipulating the settings for their chosen device.

6) Analog and Digital: Analog and Digital uses a game-show format to teach students how computers store and reproduce continuous audio signals. One student is asked to convey information about the shape of a waveform to each other using only discrete coordinates on a grid. The other student must draw the described waveform accurately.

7) Music Information Retrieval: Music Information Retrieval, introduces topics such as music recommendation and playlist selection. Students are divided into groups and asked to create playlists using methods similar to popular music recommendation services (Pandora, iTunes Genius, and Last.fm). After this activity, students should understand how math and engineering are used to organize and listen to music. Specifically, they should know how the popular music recommendation services make their recommendations.

8) The Project: Projects fall under one of four main categories. Analysis of musical instruments focuses on studying the differences between instruments and how these differences correspond to changes in the sound, waveform, and frequency spectra. Music synthesis uses computer software to simulate sounds, such as falling rain and sound effects. Students in the musical interfaces group explore new ways of interacting with music by configuring their own input device (such as a Wii remote) to control sounds generated by a computer. The final group builds and composes music for an electric monochord, a single-stringed guitar-like instrument.

(a) SMT Class 2010



(b) An individual student's monochord project presentation

Fig. 4: Each year, around twenty students (a) participate in SMT and present individual, week-long capstone projects (b).

Currently, most activities require a computer for every 1-2 students. However, the computational power required is relatively low. The students share a collection of MacBooks with an Intel Core 2 Duo processor and 1GB of RAM. With the recent advances in tablet computers, we believe that the next step is to provide each student with a device such as an Apple iPad for the week, instead of a laptop. As a research group, we have a lot of experience in development for mobile devices gained through large scale projects such as the *Philadelphia Orchestra iNotes* project. Recently, Puredata, the platform on which most of the activities are written, has been ported and compiled for Apple's iOS allowing for use in mobile audio applications [2]. Because of the tablet's ease of use and the availability of Puredata, we think it is a great next step for presenting our activities. Additionally, because the tablets are small, we can easily transport them, giving us more opportunities to perform the lessons outside of SMT, reaching a greater audience.

D. GK-12

The MET-Lab has two students who are taking part in the National Science Foundation's STEM GK-12 Fellowship Program. In this program, Drexel University has partnered with five local high schools in the School District of Philadelphia to further curriculum development and motivate interest in STEM fields. The MET-Lab students have incorporated several SMT activities into the curriculum of high school classrooms. The Musical Instrument Acoustics activity was used at Central High School during a unit on waves and the Speaker Building activity was implemented at the Girard Academic Music Program during a unit focusing on electricity and magnetism.

IV. Conclusion

Our research group is heavily involved with educational outreach activities that benefit both our research lab and the surrounding community. Furthering music appreciation through technology and technology education through music gives students a better contextual relationship to the lessons learned. Through programs like iNotes and SMT, we hope not only to educate students about music, science and technology, but to excite them about these fields.

References

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