Sonification of Interactive Physics Simulation

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Abstract. Interactive simulations are increasingly used in education, but in their present form cannot be used by learners who cannot see well. This project will address this challenge through an exploration of the emerging field of sonification and will culminate in the development of a simulation that functions without any visual component and is inspired by an electricity and magnetism simulation developed by CU's PhET project.

Background

Interactive simulations are widely used for education purposes. One group leading the charge is CU's PhET project (http://PhET.colorado.edu) which provides a large collection of free, interactive, research-based science and mathematics simulations. The PhET website has been viewed by over twenty-five million visitors, and simulations have been translated into over sixty-five languages. New PhET sims are being developed with HTML5 making them accessible across platforms and even on tablets. The source code to every simulation is publicly available on PhET's website.

Researchers at CU have worked extensively to build engaging simulations with intuitive controls and visual representations to help students develop accurate mental models of specific concepts, but the simulations have been designed entirely to suit the needs of visual learners. The controls for simulations utilize a consistent graphical interface containing click and drag objects, sliders, and radio buttons. Familiar everyday objects are shown within simulations containing cartoon-like features to emphasize important features while avoiding misleading literal interpretations (Adams et al, 2008).

Conveying visual simulations to visually impaired students may be possible using non-visual means of interaction, especially auditory means. Researchers at the University of Maryland explored teaching touchscreen gestures to visually impaired students using corrective verbal feedback and gesture sonification (Oh, Kane, & Findlater, 2013). Bruce Walker at the Georgia Institute of Technology runs the Sonification Lab which focuses on developing auditory interfaces that transmit information about data to users through sound. His team sonified a virtual aquarium where movements and characteristics of inhabiting virtual fish are translated into various timbres, frequencies, and spatially located sounds with the goal of making aquarium visits more accessible (Walker et al, 2006).

Non-auditory means used to make digital interfaces accessible to visually impaired students have been explored as well. Shaun Kane and other researchers at the University of Maryland developed inexpensive touch plates that are laid on top of touchscreen devices and can be manufactured easily with different shapes to support various users and applications (Kane, Morris, & Wobbrock, 2013).

Approach

The primary approach to making an accessible PhET simulation will be to utilize sonification, "the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" (Walker & Nees, 2011). Sonification has a wide variety of uses including specific sounds that function as alerts or alarms, audio representations of data that form the basis of musical compositions, and audio only role-playing games. Sonification has many elements at its disposal to convey information including pitch, timbre, melody, harmony, and rhythm. Through the use of time delay, dynamics, and signal movement, a sonification can add a spacial dimension to sound (Zelli, 2009). Recent applications of sonification include an audio representation of an epileptic seizure using EEG recordings taken from a patient at Stanford with epilepsy (http://blogs.kqed.org/science/2013/10/01/what-does-an-epileptic-seizure-sound-like/), and radio astronomy, a NASA project which studies celestial objects at radio frequencies and broadcasts those frequencies on the internet (http://www.radio-astronomy.net).

A promising approach to sonification that may best suit the needs of this project is Model Based Sonification (MBS) which seeks to simulate interactions with real world objects and the sounds naturally produced by them. Specifically, MBS is defined as the "general term for all concrete sonification techniques that make use of dynamic models which mathematically describe the evolution of a system in time, parameterize and configure them during initialization with the available data and offer interaction/excitation modes to the user as the interface to actively query sonic responses which depend systematically upon the temporal evolution model" (Herman, 2011). MBS is a framework which should automatically behave such that every interaction with data is accompanied by sound, the laws governing sounds are static similar to the laws of physics, sound is delivered as an immediate response to interactions, and sounds are information rich and complex. The primary interaction in MBS is to put energy into a dynamic system releasing sound as the system develops over time. This aligns well with many simulations hosted on PhET. An actual radio signal could result from wiggling a transmitter electron in the Radio Waves and Electronic Fields Lab (http://PhET.colorado.edu/en/simulation/radio-waves), or sounds could result from hanging weights on springs that convey information about the kinetic, potential, and thermal energy of each spring in the Masses and Springs Lab (http://PhET.colorado.edu/en/simulation/mass-spring-lab).

While sound can convey many things, it is not a perfect substitute for visuals. Vision uniquely allows humans to take in a large amount of information through focusing on only one element of an image at any given time. Hearing alone does not award this ability. It may be tempting to translate all focus points in an image to discrete sounds played at once, but this would only create unuseful cacophony.

In order to navigate the real world, a visually impaired person uses multiple senses. A cane is commonly used because it can convey a large amount of information. It provides a warning of objects in close proximity, and as the tip of a cane collides with an object, it can convey the texture of the object along with clues about the environment based on the reverberation (Edwards, 2011). Blind people must use different means of navigating technology as well. Most commonly, blind people use a screen reader which converts the contents of a screen into speech and nonspeech sounds. Shaun Kane has researched extensively how to make touch screens more accessible and has proposed a number of design guidelines including placing important commands near device landmarks like edges and corners, reducing time-based gesture processing, and utilizing common spatial and tactile layouts like the QWERTY keyboard (Kane, Wobbrock, & Labner, 2011). This project will need to consider carefully the needs of visually impaired users when choosing a medium and set of controls to best create an intuitive interaction with the sonification.

Development of the non-visual PhET Sonification will be driven by two common tests used by the Physics Department at CU. The Brief Electricity and Magnetism Assessment (BEMA) and Conceptual Survey of Electricity and Magnetism (CSEM) are two similar assessments that test student learning and conceptual understanding of topics in Electricity and Magnetism. The average BEMA pretest score at the University of Colorado Boulder is 27% and the average BEMA posttest score is 61% (Pollock, 2008). The goal of the sonification should be to teach material necessary to understand and solve relevant problems on these tests.

Design Considerations

1. Technologies must require absolutely no vision to use. Learners from slight visual impairment to blindness should be able to utilize technology so long as they do not also have a hearing impairment.
2. In alignment with PhET's goal of making educational simulations easily accessible, higher precedence will be placed on technical solutions which allow the sonification to be interacted with on the web or downloaded easily and run without requiring extra software.
3. Only sonification techniques that require little to no training from non-visual learners to understand will be considered. The vOICe project is an interesting experiment which attempts to teach synthetic vision through converting captured images into sounds (http://www.seeingwithsound.com). For the purposes of this project, a similar approach to conveying information is unfeasible due to the extensive length of time required to learn to derive visual meaning from sounds.

4. Speech will be used only when necessary to convey specific information. Non-speech sounds will encourage learning through discovery and interaction while too much verbal feedback could lead to static cues that simply tell learners the answer.
5. The best approach may not necessarily be a translation of visuals into sound taken from the selected PhET simulation. Instead it will be worth understanding the learning goals of the PhET simulation, and determining the best possible means of conveying that information through non-visual interaction and presentation techniques.

Technology

I will experiment with a number of programming languages. Max MSP is a visual programming language primarily used by musicians and performers (http://cycling74.com). Max MSP is one of the most powerful and robust languages for sound design and the creation of algorithmic music and should prove useful for building dynamic sonifications. However, initial research suggests that programs built with Max MSP are not web embeddable. Javascript now has a number of sound creation libraries including Howler.js (https://github.com/goldfire/howler.js) and SoundJS (http://www.createjs.com/#!/SoundJS). If web technologies prove robust enough to handle complex sonification, I will explore building a final sonification entirely with HTML5 and Javascript.

For audio playback, I will utilize traditional stereo systems like headphones and computer speakers. I may also experiment with multi-channel systems which enable more freedom in controlling the spatialization of sound. For example, I am trained to use the hemispherical speakers, half dome objects containing five speakers that the Boulder Laptop Orchestra performs with (http://www.colorado.edu/music/ensembles/blork-boulder-laptop-orchestra). Hemispherical speakers are capable of precisely emulating the directions of sounds produced by acoustic instruments.

The sonification will be controlled through interacting with a computer or tablet device. Some modern tablets such as the Fujitsu Ultrasonic Tablet use haptic technology, vibrations that convey tactile sensations. The Ultrasonic Tablet in particular can convey a sense of slipperiness and roughness by varying the friction between the screen's surface and the user's fingers. Exploring haptic sensory technology will be viewed as a stretch goal for this project.

Another controller that may prove useful is the LeapMotion Controller (https://www.leapmotion.com). The LeapMotion controller can track precise hand movements at a rate of two hundred frames per second within a three dimensional space around the controller. A three dimensional space may contain a sonic representation of a visualization in which sounds are triggered as the user moves his/her hands above the controller. For example, a user could specify the placement of a charge in a 3d representation of an electric field and see how the charge reacts (http://PhET.colorado.edu/en/simulation/efield).

Development Plan and Timeline

The project will consist of two main phases: research and development. During the research phase, I will explore a wide variety of sonifications, and in order to best understand how notable sonifications function, I will attempt to provide my own implementations. At the end of the research phase I should have an idea of what technologies are effective and working knowledge of useful methods to conveying various types of data. At the end of January 2015 at the latest, I will select a reasonable PhET simulation on a topic in Electricity and Magnetism and work to develop an extensive emulation of it that contains no visual component.

A stretch goal of this project will be to study and evaluate the effectiveness of the sonification via human research. Visually impaired and sighted participants will be monitored on their usage of the sonification and tested on whether they absorb the intended material. I will make the decision to pursue human research depending on progress of the project by the end of January 2015. (The Student IRB takes two to eight weeks in review meaning I should have at a minimum four weeks to conduct research.)

Collaboration

A team led by Professor Clayton Lewis, Professor Michael Theodore, and Professor Noah Finkelstein has received an ATLAS Seed grant to evaluate approaches and techniques to making PhET simulations accessible to learners who cannot see well. I will work closely with this team and will share all relevant findings in sonification.

References

Adams W. K. , Reid S., LeMaster R., McKagan S. B., Perkins K. K., Dubson M., & Wieman C. E. (2008). A Study of Educational Simulations Part II - Interface Design. Journal of Interactive Learning Research, 19(4), 551-577.

Edwards, A. D. N. (2011). Auditory display in assistive technology. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, The Sonification Handbook, chapter 17, pages 431–453. Logos Publishing House, Berlin, Germany.

Hermann, T. (2011). Model-based sonification. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, The Sonification Handbook, chapter 16, pages 399–427. Logos Publishing House, Berlin, Germany.

Hermann, T., Hunt, A., Neuhoff, J. G., editors (2011). *The Sonification Handbook*. Logos Publishing House, Berlin, Germany.

Kane, S.K., Morris, M.R., and Wobbrock, J.O. (2013). Touchplates: low-cost tactile overlays for visually impaired touch screen users. Proceedings of ASSETS '13, ACM, 8 pages.

Kane, S.K., Wobbrock, J.O. and Ladner, R.E. (2011). Usable gestures for blind people: understanding preference and performance. Proceedings of CHI '11,ACM, 413-422.

Oh, U., Kane, S.K., and Findlater, L. (2013). Follow that sound: using sonification and corrective verbal feedback to teach touchscreen gestures. Proceedings of ASSETS '13, ACM, 8 pages.

Pollock S. (2008). Comparing student learning with multiple research-based conceptual surveys: CSEM and BEMA., PERC Proceedings 2008, AIP Press.

Walker, B. N., Godfrey M. T., Orlosky, J. E., Bruce, C., & Sanford, J. (2006). Aquarium sonification: Soundscapes for accessible dynamic informal learning environments. *Proceedings of the International Conference on Auditory Display (ICAD 2006)*, London, England (20-24 June). pp. 238-241.

Walker, B. N. and Nees, M. A. (2011). Theory of sonification. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, The Sonification Handbook, chapter 2, pages 9–39. Logos Publishing House, Berlin, Germany.

Zelli, B. (2009) Space and Computer Music: A Survey of Methods, Systems, and Musical Implications. Online at http://cec.sonus.ca/econtact/11_4/zelli_space.html.