Enhancing Science Inquiry Via Sound and Music

Wallace Feurzeig, *feurzeig@bbn.com*

Department of Educational Technology, BBN Technologies, Cambridge, MA, USA

Eric Neumann, ***eneumann@alum.mit.edu***
Department of Educational Technology, BBN Technologies, Cambridge, MA, USA

Abstract

We describe the design of a software environment and a set of laboratory tools to enhance and enliven science learning through hands-on explorations, investigations, and student research projects in the domain of musical acoustics. Music is a powerfully riveting mode of expression and communication for high school students. A typical student's world is inundated with sounds: iPods, TV, CDs, radio, bands, rock, rap, funk, salsa. Students are receptive to music of all kinds. Many students perform and create their own. This contrasts with science, which fails to hold the interest of all but a few high school students. Approximately 80% of US students take first-year biology or earth science. The proportion drops to about 40% for chemistry and declines dramatically to under 10% for physics. Indeed, in areas where students are less concerned about college entry science requirements, these numbers are even lower.

Computer technology can provide a uniquely valuable way to build a bridge between the frequently disparate student interest worlds of music and science and to provide an alternate path to the serious study of computer science itself. Many kinds of natural, mechanical, and musical sounds that students find interesting are accessible to computers—heart sounds, birdsong, speech, thunder, ocean waves, polyrhythms. The rich sound-generation capabilities made possible by integrating computer-controlled synthesizers with software facilities for exploration and experiment can foster a lively introduction to scientific thinking, by creating an environment that enables students to generate and investigate an incredible variety of sounds and music through information processing techniques. Constructionist learning activities in the domain of sound have an extraordinary potential for providing a compelling pathway into inquiry, which is as an integral part of science education.

Computer visualization techniques have proven valuable for enhancing student interest and involvement in science investigations. Computer sonification techniques have received much less attention. Yet complex behaviors can often be better understood by associating sound with displays. The addition of sound brings an extra dimension to our experience and understanding of real world phenomena. Data originating outside the acoustic domain—such as seismic and meteorological data—can be transformed to audible range. Students are thereby able to *hear* natural data produced by phenomena such as the sunspot cycle and *listen* to long-term changes in barometric pressure or global warming patterns. We are certain that a significantly larger fraction of students will be drawn to science through introductory activities that exploit sound and music to enliven inquiry. We show vignettes of student work to illustrate the potential of such activities to augment and heighten student engagement in science exploration and inquiry.

Keywords

Science Education, Computer Sonification, Musical Acoustics, Auditory DisplaysEnhancing Science Inquiry Via Sound and Music

Enhancing Science Inquiry via Sound and Music

The sound-generation and acoustic analysis capabilities of computers offer very specific benefits for science education. The simplest is the sheer appeal of sound for students. In recent years, sonification methods have been effectively employed in science research (Shinn-Cunningham, 1998; Kramer, 1997; Kramer, 1994; Bargar, 1994; Scaletti & Craig, 1990). Thus far, however, their use in science education is virtually non-existent. Yet computer sonification, enabling science activities with sounds and music, can have the same power as computer visualization to capture students' interest and sustain their engagement. Sonic representations of phenomena can greatly aid students whose quantitative or spatial organization is less developed or who have difficulty acquiring concepts taught solely with textual or visual representations.

The use of sound is particularly valuable for investigating oscillatory systems, which are fundamental constituents of many physical and biological processes—and also of music. Since the concepts of sound and oscillation are nearly inseparable at a fundamental level, the use of sound is natural for studying such systems. Further, the physical product of a perfect linear oscillator is a pure tone, and the addition of pure tones leads naturally to an exploration of what makes a sound pleasing or musical. This introduces an aesthetic dimension to the science course, one that is often lacking for many students.

By coupling oscillators to MIDI devices such as synthesizers we can produce a rich variety of sounds. From heartbeats and cricket chirps to earthquakes and the periodic explosions of Old Faithful, the natural world offers many examples of oscillating systems that have nearly discontinuous behaviors. Phenomena like these are best modeled by percussive sounds—typically short-lived sounds that “go off” whenever their controlling oscillator reaches a pre-defined phase angle. When generated by a single oscillator, the sounds are repetitive and rhythmically uninteresting. When one couples oscillators together however, even in very simple ways, the resulting rhythms are often complex and fascinating—musically as well as mathematically and physically (Fergemann, 1993; Schneck, 1992.) Systems of coupled oscillators are natural candidates for sonification. By making their complex dynamic behaviors palpable as rhythmic patterns, sonification brings a new experiential dimension to the study of periodic and quasi-periodic systems and provides a powerful impetus to scientific inquiry.

An oscillation has three characteristics—amplitude, frequency, and phase. The concept of phase, which is surely the least understood of these, can be brought to life through the study of oscillatory systems. Sonic representation can strongly complement visual representation of oscillatory system behaviors. Our ears are sensitive to features that our eyes cannot perceive. Although the period of oscillation of light is incredibly short—on the order of 10^{-15} seconds—our visual apparatus is unable to perceive frequencies much in excess of 10 Hz. However, our ears are sensitive to frequencies three orders of magnitude greater—they enable us to experience complex processes that involve the superposition of multiple frequencies and that occur in less than a millisecond. Our ears are better equipped to extract meaning from these phenomena than our eyes are for deciphering an equivalent burst of light.

In addition to responsiveness across a large frequency range, our ears are extremely sensitive to phase shifts. For example, changes in the relative phases of signals presented to our ears are readily perceived as alterations in the direction of the source. Thus, the remarkable ability of humans to determine the provenance of a sound can be used to introduce the concept of phase.

In the course of sound-enhanced investigations of physical, biological, and musical processes, students’ understanding of the associated mathematical processes and concepts can be greatly deepened by sonic representations. Mathematical processes such as function generation, iteration, recursion, exponentiation, and algorithmic operation can be sonified as well as visualized. Through the use of audio displays, mathematical behaviors can be heard as well as seen. Such “in vivo” aural experiences can help students to gain new mathematical insights and advance their understanding of mathematical ideas they previously regarded as inaccessible or meaningless.

To foster mathematical and scientific inquiry, we are developing *SoundLab*, a computer system designed to enable students to create, explore, display, sonify, and analyze sounds of many kinds. SoundLab is a visual modeling environment for introducing the study of oscillators and oscillatory systems, through experiences coupled to sound. The system hardware includes a computer and a Musical Instrument Digital Interface (MIDI) connected digital sample synthesizer. We have demonstrated preliminary versions of SoundLab programs to science educators. Many have been excited by the realization that computer capabilities for representing biological and physical processes sonically as well as visually have significant potential for enlivening science exploration and inquiry activities.

The graphic tools under development in SoundLab enable students to “see” the sounds that they hear, decomposed into their fundamental frequency modes via fast Fourier transform methods. Using a computer equipped with an audio pick-up and appropriate software, students are able to sample and synthesize sounds of all kinds. The coincidence of aural and visual sensory inputs helps students learn the physical meaning of frequency, amplitude, phase, resonance, and linear superposition. They will be gaining a natural introduction to wave behavior and the fundamental concepts of acoustics. There can be few more powerful ways of learning about waves than to experience them both visually and aurally. Coupling sound to visual models of wave behavior provides a powerful experimental environment for engaging students in science explorations involving the analysis and synthesis of complex sounds.

SoundLab enables the development of new sonification-based techniques expressly designed for science education. Students can explore the structure of familiar sounds and identify their characteristic features. SoundLab tools enable users to hear sounds over a wide range of frequencies and through a variety of filters. Students can separate, view, and hear each component of a sound—even if its source is initially outside the audible range. Modeling labs in SoundLab enable students to generate sounds, investigate how sound interacts with the environment, and explore the effect of timbre, envelope, and pitch in music.

It is not enough, of course, to provide students with powerful tools for producing, analyzing, and manipulating sounds. They need to be guided in the use of the tools, presented with interesting and carefully sequenced challenges, and brought to the point where they can carry out their own investigations, and perhaps develop their own applications. Throughout, emphasis must be placed on the *process* that produces the sounds, whether these are data-driven or algorithmically generated. With appropriate preparation and guidance, students can take on problems and projects in various science and music domains, such as the following.

Biology

- generating waveforms from recordings of animal calls and songs
- analyzing the sounds of dolphins, bats, wolves, birds, monkeys, . . .
- generating bird songs that mimic those observed in nature
- modeling the behavior of coupled oscillators in biological systems (circadian rhythms)
- modeling the dynamics of the electrical control system of the human heart
- investigating the psychoacoustics of perception (what we “hear” when we hear)

Mathematics

- seeing sounds and hearing graphs: representing amplitude and frequency across time
- sonifying and studying the behavior of functions, sequences, and limiting processes
- investigating the harmony in trigonometry: sines, cosines, and phase

Physics

- creating audio displays of waves and oscillators (wave mechanics)
- masking unpleasant sounds (noise pollution) by filtering or by *adding* sound
- using audio signals to measure range and position of objects (sonar echolocation)
- investigating the behavior of physical oscillators, e.g. spring-mass systems
- using sound to analyze time-series data from earthquakes, weather, and sunspots
- generating racing car sounds and adding Doppler effects
- analyzing the waveform of a ping pong ball's impacts to determine its speed

Musical Acoustics

- creating “pleasant” and “unpleasant” music and characterizing key differences
- creating music sequences with specified rhythmic or harmonic patterns
- generating musically interesting polyrhythms algorithmically
- turning humpback whale songs into Fats Waller or Bono tunes
- creating complex tones by steadily increasing the rate of discrete rhythm patterns
- generating rhythmic tone sequences in music via coupled oscillators
- building virtual music instruments using filters and transfer functions

These investigative activities and projects are designed to provide students with the basic scientific knowledge and inquiry skills to prepare them to construct their own sound and music artifacts. The SoundLab software is designed to support their investigations and constructions. A brief description of some of the modeling tools that comprise SoundLab follows.

SampleView. This tool enables students to capture, display, and hear sound samples of all kinds—simple tones, music, biological sounds, data originating from non-acoustic sources that have been transformed to the acoustic domain. During data acquisition the sound stream will be viewable on a computer screen. The program has facilities for successive magnification of all or selected parts of the sample material, to enable one to see and hear the fine structure of the sound. Students are able to explore and investigate live and recorded sounds as well as non-acoustic time series data, animal sounds (dolphins, mocking birds, whales, wolves, bats), earthquake and underground detonation data, songs, musical instruments, and speech.

Harmonic Synthesizer. This tool enables students to construct sounds out of harmonic components that can vary in frequency, amplitude, and phase. A varied set of waveforms—square waves, sawtooths, chords, and vowel sounds—is provided. MIDI can be used to input the harmonics plus custom wave forms. Students are able to see and hear the results of varying these parameters, either in the sound components or in the composite sound. The system supports multiple linked representations of the waveforms. Student activities include creating or modifying one or more harmonic components so as to compose a sound that duplicates a given sound. Use of the program can enhance the students’ understanding of phase relationships among harmonics.

MidiPhasor. This tool enables students to design and control the operation of systems of coupled oscillators. Students can create complex rhythms and polyrhythms—close emulations of classical, jazz, and rock forms—as well as highly varied original rhythmic patterns. At the same time they can gain both aural and visual experience of some fundamental concepts of number theory, such as primality and incommensurability, and experience the utility of mathematics in aiding their rhythmic designs. Systems of coupled oscillators are fundamental components, not only in acoustic phenomena, but in virtually all natural systems. The program supports a rhythmic representation of the phase relationships between two oscillators. Users can vary the rates of each oscillator and the coupling strength between them. The oscillators can be coupled so as to produce complex and sometimes chaotic rhythmic patterns that are presented both graphically and aurally. The program outputs can be used with a synthesizer to generate a rich variety of timbral effects, producing compelling sound patterns and music.

Dynamics Construction Kit. This tool provides students an environment for building their own aural and visual dynamical systems. Systems can be constructed out of five kinds of objects—Inputs, Links, Clocks, Responders, and Composites. Inputs include keyboard and MIDI sound sources. Links have parameters such as propagation delay time and refractory period. Clocks (oscillators) have parameters such as period, phase, perturbation function, and coupling strength. Responders include MIDI objects (tones, and tonal sequences), graphics objects (music notation and events, e.g. pitch and duration as a function of channel), and number objects. Composites are higher-level objects constructed from the five basic objects and other composites. As a program runs, the currently active objects are highlighted and their links animated to show the passage of signal and control data. The other SoundLab tools complement the use of this facility in enabling students to develop sound and music generation systems of their own design.

Some of these capabilities are accessible via widely available software tools such as Audacity. However. their interfaces are not specifically tailored to facilitate use by pre-college students. SoundLab tools were crafted to exploit the enormous appeal that electronic music and sound generation have for high school students, in a way that provides educationally productive science learning experiences. SoundLab projects offer users bountiful opportunities for experiencing the spirit and sense of science inquiry. Some students will use SoundLab's sound processing capabilities in an indiscriminate fashion without learning any science along the way. Most, however, will find their work with SoundLab instructive as well as enjoyable.

The following scenarios illustrate the flavor of student interactions with SoundLab. The first shows the work of a tenth-grade biology student; the second, that of a ninth-grade general science student; the third, that of a scientifically sophisticated high school physics student.

1. Analysis and Synthesis of Mockingbird Song

Rachel wanted to investigate the song of one of her favorite birds, the mockingbird. She knew that these birds produce remarkable calls with many variations, and that they often imitate the songs of other birds. There was a highly vocal mockingbird near her house. She recorded the bird’s song on cassette. After she had collected a few hours of song, she took the recordings to her biology class. She reviewed her tape to identify and mark the diverse song segments she found most interesting. Using the SoundLab SampleView module, she entered eleven different sound segments. Viewing the waveforms (Figure 1), she observed definite clusters as groups of waves. She selected those regions and played them back. She identified the groups as the various chirps of the mockingbird’s song. Some sounded distinctly different than others.

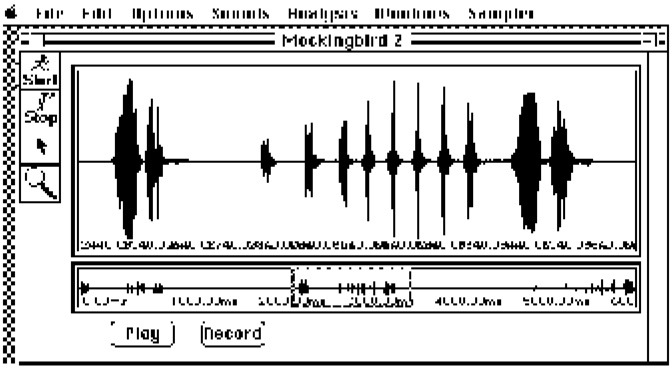

Figure 1. A set of varying mockingbird chirps, viewed across 1 second

She could not easily discern those differences visually from the sample, so she collected a few examples and grouped them by ear. She then used the SoundLab SoundScape tool to investigate the “composition” of these chirps. She displayed the pattern of one chirp (Figure 2).

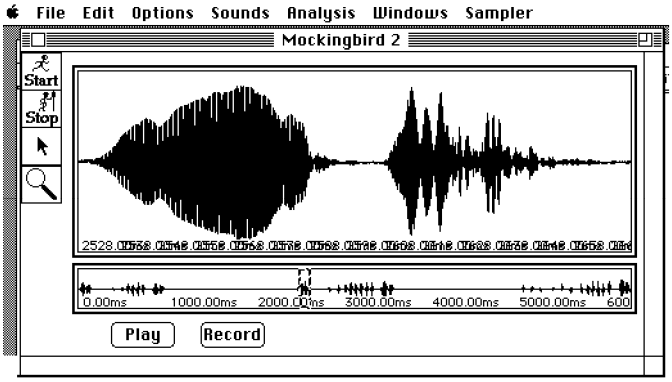

Figure 2. Close-up of the left-most mockingbird chirp from above

She used the SoundLab sonification tool to investigate the sounds associated with the graph’s regions. As she slid a cursor along the x-axis, a simple tone rose in pitch; for every doubling of the position of x, the pitch increased in a way that sounded like the chromatic scale. When she placed the cursor over the ridge pattern, the tone produced was near in pitch to that of the sample. The pattern clearly contained pitch information, but she wondered if the distinctive sound of the chirp could be clearly shown on the graph of the waveform. She used the zoom tool for a closer inspection of the waveform pattern (Figure 3).

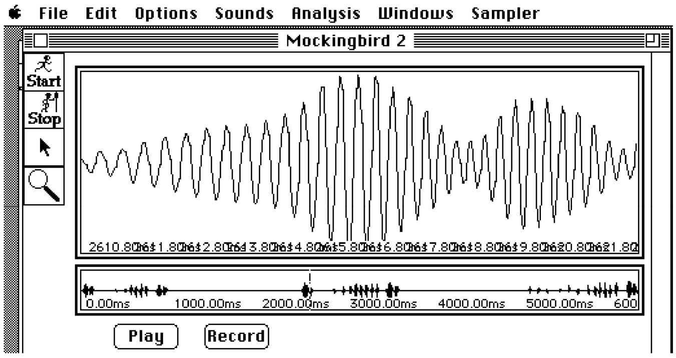

Figure 3. Highly enlarged view of the above chirp, illustrating the oscillating waveform

She now saw that it had a finer set of features; there were actually two ridges whose heights waver across a short time interval. She used the sonification tool to play multiple tones whose pitches followed the tops of both ridges. The new computer-generated sound was a great deal closer to the chirp—its attack and duration were similar. She repeated this waveform analysis and sound synthesis for similar and dissimilar chirps and annotated each chirp’s characteristics (e.g., its pattern of single or multiple pitches, and their attack and duration).

Rachel used her results to piece together the various chirps within a song segment (Figure 4). She saw the regular modulated waveform. She observed that the chirps formed patterns that were related to the various calls she was able to distinguish with her ears. She was amazed by the complexity of each call and the fact that mockingbirds can produce such a rich variety of songs.

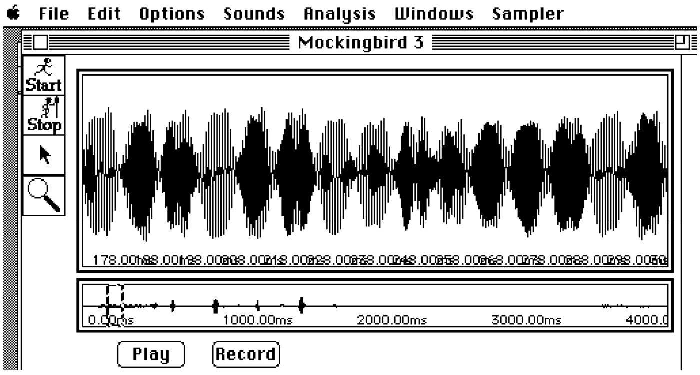

Figure 4. Close-up of a mockingbird warble

She compared these songs with other sampled bird songs obtained from the Cornell Ornithology Laboratory. After comparing the different samples by ear, she identified some of the mockingbird songs with the bird songs they appear to mock. She attempted to find the differences between the original and imitation songs first by ear, then by using the SoundLab analysis tools. After writing up her results for her biology project report, she wondered if she could elicit calls from other birds in the wild by using the mockingbird calls. She thought she might produce her own set of calls, put them on tape and play them back to the birds in the wild. She wondered if she could 'mock' the mockingbird song.

2. Using SoundLab to Create Music

Why should kids who are interested in drumming, rap, and rhythmic composition come to care about notions like phase and ratio? Rashad, a ninth-grade high school student, was turned off by math and science, but he was greatly interested in making and performing music. His music idols included M.C. Hammer, Michael Jackson, and Prince, and he was up with the latest rap hits. He would love to create his own electronic piece, but he was unfamiliar with the relevant technology. His science teacher, Mr. Owens, suggested that Rashad use SoundLab to put together a piece from Rashad's own music material for his science project. Rashad was excited by this idea.

He explained to Mr. Owens that he wanted to lay down some rhythm tracks and put music and various other sounds on top of that. He wanted to make a strongly rhythmic piece with sounds that repeat "though not always exactly." Mr. Owens asked Rashad what sort of sounds he wanted to include. Rashad replied, "I want some clapping, some shouts, and some wild big sounds!" His teacher lent Rashad a cassette recorder to collect and capture these sounds.

Rashad recorded some sounds directly from the street: car horns, sirens, laughter. He listened to some rap singing on his boom box and recorded the bits he liked. After a week of recording he asked to use SoundLab. Mr. Owens started SoundLab and activated the SampleView module. Rashad connected the tape output to the computer's sound port. He soon realized that he had several hours of recordings—a lot more than could be stored. So he reviewed the tape to select the segments he liked best. He used the record button in the SampleView module to input his selected segments. His sounds were sent to the SoundLab sampler and mapped to the various keys on the synthesizer. He heard each of his sounds by playing a corresponding note on the keyboard.

He commanded the computer to play the sounds on the synthesizer and arranged them sequentially using the MIDI control facility. After a few attempts at arrangement, he wanted to get rhythmic sound patterns that repeated indefinitely. Mr. Owens suggested using a MIDI periodic oscillator (a *clock*) in the SoundLab Dynamic Construction Kit to control the repetitive sequence of sound playback. Rashad created a clock and added the sequence of sounds around its circumference (Figure 5.) He started the clock and immediately heard the sound pattern.

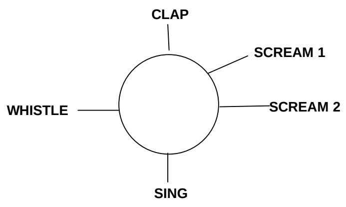

Figure 5. Rashad's Clock

"This is wild!" he exclaimed, "Can I move the sounds? How do I get the sounds to play a little sooner or later?" "You can grab the labeled sound symbols at any position around the clock and move them to a new position or phase." "So the phase tells what time the sounds should be played every time the clock goes around!" He was enthusiastic. "Can I get another clock with different sound rhythms to play along with this one at the same time?" "Sure, as many clocks as you like" replied Mr. Owens, "but think about how you can get them to work together to do what you want."

Rashad created another clock, placed some other sounds around it and started it playing. More sounds were being played, but the overall rhythmic pattern was not changed, and was not more intricate as he would like. He saw that the two clocks were running in synchrony. To change this, he used the mouse to grab the arm of one of the clocks to stop it from playing, and released it a second later. The rhythmic pattern shifted somewhat. f

"It's still the same beat!" he complained, "I want something more hip!" Mr. Owens tried to get Rashad to think about the problem differently. "Why don't you try changing the speed of one clock relative to the other?" He showed Rashad how to alter the clock speeds and phase parameters via a dialog box. The current rate value was 1.0. Rashad sped it up. He tried a value of 10. "That sounds crazy, it's too fast!"

Next he tried a speed of 3 and found the result more pleasing. After trying other values, he found that basic rhythms were produced by small integer values, but he could make more interesting ones using decimal values like 2.5 or 1.33. At times he needed to play with the hundredth decimal place to get the beat to sound "just right". He also tried changing the speed of the other clock and began noticing similarities between rhythms whose clock values seemed to be quite different.

" That's funny, I get the same pattern if the clock speeds are 1.0 and 2.5 as when they are 2.0 and 5.0, only it's twice as fast." "Why don't you try comparing the ratio of the clock speeds for similar patterns?" "What do you mean by ratio?" Mr. Owens explained the concept of ratio.

Rashad began to understand the invariant rhythmic relationship between the two pairs of clocks. He wondered why this relationship is expressed by a mathematical operation, division. Putting that aside for the moment, he tried next to set the rhythmic patterns for his entire piece. He played some of his extended composition to Mr. Owens, who saw that Rashad was now using four clocks. "You know, if you connect the clocks to each other so they affect each other's phases, the patterns might get more interesting, even with just two clocks!" Rashad began coupling the clocks. This allowed him to generate more "fascinating rhythms" while raising new math and science questions about how to design "wilder" and more-pleasing rhythmic patterns.

In the constructive context of music synthesis, mathematics and science concepts such as variable, period, frequency, amplitude, phase, oscillation, phase shift, periodicity, steady state, and perturbation took on concrete meaning and became real for Rashad.

Through such work, the sense and value of science inquiry, even at a naive beginner's level, becomes apparent to "non-science" students like Rashad and has the potential to set the stage for further engagement and intellectual development.

3. Generating Music with Chaos in Coupled Oscillators

Other students, scientifically more advanced than Rashid, have used SoundLab to investigate the application of mathematics and physics for generating rhythmically complex and aesthetically interesting music. Two sophisticated high school juniors conducted intensive independent research employing the SoundLab MidiPhasor and Dynamic Construction Kit tools. (Fergemann, 1993; Schneck, 1992).

The work of one of these students is described next. David started his project by studying the prior research on dynamic models of physiological rhythms in organ systems. This body of work is comprehensively summarized in Glass and Mackey (1988). A paradigmatic example of these dynamic mathematical models is that describing the electrical behavior of the heart's cardiac rhythms under normal as well as pathological conditions such as arrythymias. Systems like this can exhibit their oscillatory behaviors as rhythmic patterns, ranging from periodic to chaotic.

David was interested in developing dynamic mathematical models of oscillatory systems with such behaviors in SoundLab in order to express their often-complex rhythmic patterns sonically. He sought to show that a sonic representation could significantly augment one's insight into the behavior of such systems, particularly when they exhibit chaotic dynamics. Sonification can provide more information than a graph alone can give, making it easier to recognize periodicity, quasi-periodicity, and chaos, while creating interesting musical effects at the same time.

Oscillatory systems with regular perturbations can be depicted as in Figure 6, which shows a rotating oscillator that is perturbed at regular intervals t by a stimulus at a fixed distance b.

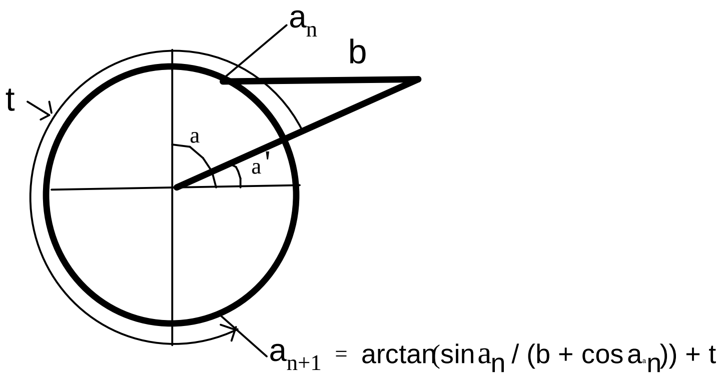

Figure 6. Graphical representation of a single perturbation and successive iterations

The result of a single perturbation is given by $a^I = \arctan(\sin a / (b + \cos a))$ where a is the original phase of the oscillator and a^I is the new phase. Successive iterations can be represented by the iterated function $a_{n+1} = \arctan(\sin a_n / (b + \cos a_n)) + t$. Each time the oscillator passes $a = 0$ an event, such as a heartbeat, occurs. This dynamic model lends itself well to sonification.

To create sound sequences, notes are placed at many points around the circle. A note is played whenever the oscillator rotates past it. Careful placement of the notes can generate interesting rhythmic and melodic sequences. With some values of t and b, the oscillator produces rhythms that are chaotic and form short, unstable patterns that change unpredictably over time. Subtle differences in t and b can cause a sequence of notes to be played, skipped, or repeated, making the changes in dynamics clearer and often producing sequences that are musically compelling.

David used a Yamaha SY-99 synthesizer with SoundLab to investigate the use of sound for representing the dynamics of coupled oscillator systems. He created two rotating clocks with MidiPhasor. The first clock behaved like the oscillator described above. It had notes of different pitches and volumes placed around it. The synthesizer played these notes whenever the clock rotated past them. The second clock rotated at a different constant speed determined by t and provided the stimuli to the first clock by causing a perturbation in it after each revolution. For any combination of t and b, the behavior of the oscillator system could be periodic, quasi-periodic, or chaotic. David showed how these behaviors can be sonified to produce a number of musical effects and how these effects can help clarify the differences between periodicity and mathematical chaos. He used the mathematlical appliation *Mathematica* to create bifurcation graphs showing the characteristic behaviors of the clocks for a wide range of values of b and t.

David concluded his project by conducting an extensive analysis of possible system behaviors. He showed that periodicity occurs when the oscillators “phase lock,” i.e., when after M cycles of the first clock and N cycles of the second, the oscillators’ behavior repeats exactly. The simplest form of periodicity is when b > 2. Here, the oscillators show phase locking when t > 0.5. Since M = 1 in these cases, a sequence of notes repeats the same way at each perturbation. When b is slightly greater than 1, however, the periodicity begins to change into chaos, and the sounds lose their regular rhythms though the music can still be controlled. Some regions of the circle tend to be repeated less often than others. Notes placed in these regions can add variety to the music. Short, frequently changing rhythmic patterns often form, offering greater variety in the melody and rhythms than phase-locking. At b = 1 some interesting rhythmic patterns occur. Different phase-locking zones form over a range of t values. These regions overlap in ways that produce very complex rhythms. In some cases the sound created resembles the irregular or changing meter frequently found in twentieth-century music.

These scenarios suggest how high school students at different levels of sophistication can use computer sonification tools in science explorations and investigations. There have been a few studies exploring the use of sonification by high school students (Upson, 2002; Stanionis, 1992.) These short-term interventions have not led to adoptions by schools. Although college courses employing sonification tools are offered at some institutions, (Berklee, 2010a; Berklee, 2010b; Sydney, 2010), few if any such courses are currently offered in U.S. high schools.

The educational potential of this unique approach to introducing science inquiry at pre-college levels has yet to be realized. The additional sensory contribution made possible by the use of sound as an investigatory medium is an innovation waiting to happen. Thus far, in the words of the bard, “The eye of man hath not heard, the ear of man hath not seen . . .” (Shakespeare, circa 1595).

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