Project Notes

Contents

Table of Contents

Knowledge Gaps

This list provides a brief overview of the major knowledge gaps for the project, how they were resolved, and where to find the information.

Knowledge gap	Resolved By	Information is located
Sonification Techniques	Reading	SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis; Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display
Sonification Relevance	Reading	All sources concerned with sonification (e.g. SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis)
Sound Analysis	Reading	All sources concerned with music (e.g. SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis)
Fourier Series	Reading	Fractal Music : The Mathematics Behind "Techno" Music
Instrument Use	Testing	lab notebook
Software Use	Testing	lab notebook

Literature Search Parameters

These searches were performed between 9/16/18 and 1/2/2019.
This is a list of the keywords and databases used during this project.

Database/search engine	Keywords
WPI library search engine	Sonification, technique(s), sound, aesthetics, avoiding alarm fatigue, minimal training, spatial sound synthesis, parameter-mapping sonification, interactive sonification, alarm fatigue (sonifeye), Fractal, music, mathematics, Fourier Series, physical modeling, Curvature, e-learning, learner's styles
Google Scholar	Sonification, education, learning style, sonified graphs

General Background

- There are four main types of sonification, as described in Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display (the words taken directly from this source.)

1. Audification, described in Chapter 12 of *The Handbook*. This is a method that interprets a data sequence directly as an audio waveform.
2. Parameter mapping, described in Chapter 15. Changes in the sound are mapped from the data.
3. Stream-based sonification—features emerge through stream-based gestalts, similar to parameter mapping and, likewise, described in Chapter 15.
4. Model-based sonification, described in Chapter 16. Data are turned into dynamic models that the user "excites" to explore data structures via the acoustic feedback. ≫

- (Same paper) Continuous trajectories through space could be mapped to time, and work well with parameter-mapping, but this gives only one locational look at the data
- Mapping of many data sets can become processor-intense

- (The Sonification Handbook Chapter 18.2): There is a significant difference between hearing and listening, and what Gaver calls "everyday listening" and "musical listening." In everyday listening, we observe generally properties of sound to figure out qualities of an object associated with an object, like its size, material, etc. In musical listening, we play close attention to the sound in and of itself, and analyze it as we hear it.
    - In order for sonification to be effective at presenting data, it must be presented in a way that takes into account how the user is listening. Generally, the listener needs to be doing "musical listening," but this can be hard if the data is presented in a way that is hard to differentiate from noise.
- (Chapter 18.3.1): Various studies have showed that having representative/analogous sounds (real world sounds associated with what the data is presenting, for example, a glass-breaking sound to signify bottles breaking) in sonification can make it more effective and less annoying to the user.

- (Chapter 18.3.2) This book also talked about weather sonification (a path I was originally somewhat interested in), and studies that show that weather forecast data rendered as sound and then played regularly on the radio would not be found annoying or distracting.
- (Chapter 18.4) Sonification has been used for a while in computer debugging. An advantage of sonification is that the brain can passively listen to auditory input. The book mentions various “attempts at [computer] program sonification”
    - Simple mapping of “a data item to a chromatic pitch in the 128-tone range”
    - Aestheticism allowed more comprehensible output
    - (citation people) “mapped chaotic attractor functions to musical structures in which the functions’ similar but never-the-same regions could be clearly heard”
    - “1994 Northridge, California earthquake” along with the bubble-sort algorithm were sonified using musical forms
    - Using sonification to complement visual displays was also effective
    - Book then lists various developed “program sonification tools” and gives some information about each one
- (Chapter 18.5) Gaver developed a sonification system in Finder to measure progress by the sound of a jug being filled up
- (Chapter 18.6) Some challenges in sonification include
    - Sonifications being annoying, hard to listen to, or distracting
    - Aestheticism
    - Being comprehendible and hearable
- (18.6.2) “Emotive associations” are important to consider
    - There is some emotion conveyed when presenting weather information, like the happy emotion from hearing nice weather, which is not conveyed when sonified
        - One group tried to solve this by developing an “Emo-Map” which connected weather vectors with emotions
- (18.6.3) There seemed to be a lack of “formal studies” about which “ecology” is best perceived by users (voice vs sound effects vs combinations, etc.)
- (18.7.3) Soundscapes are a cool way of relating real world information in sonifaction, as natural, real-world sounds are built into the soundscape

- (18.7.5) Physical modeling is cool, because instead of direct parameter-mapping, data is mapped to a physical model which is then mapped to sound, which allows for more realistic and applicable sonifcations

SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis

Source citation

(Roodaki, Navab, Eslami, Stapleton, & Navab, 2017)
https://ieeexplore-ieee-org.ezproxy.wpi.edu/document/8007327/
Roodaki, H., Navab, N., Eslami, A., Stapleton, C., & Navab, N. (2017). SonifEye: Sonification of Visual Information Using Physical Modeling Sound Synthesis. *IEEE Transactions on Visualization and Computer Graphics, 23*(11), 2366-2371. doi:10.1109/tvcg.2017.2734327

Source type

Journal Article

Keywords

Sonifaction, techniques, aesthetics, avoiding alarm fatigue, minimal training

Summary

For tasks requiring high precision, visual feedback doesn't always cut it, so this paper used sonifications for feedback. They tested poking objects, and found good results for sonification, also good but less good results for combining visual feedback and sonification. Alarm fatigue is really the big problem that is eliminated by sonification. Also, mapping accuracy to pitch and timbre, not just pitch, makes things more intuitive, and continuous signaling is distracting.
Note: for other articles see abstract

Reason for Interest

This article contains a technique for sonification, which is what I was looking for in my initial research.

Notes

Abstract

- There are advantages to "Sonic interaction as a technique for conveying information" over standard visual methods, especially due to elimination of distraction
- "aesthetics, the cognitive effort required for perceiving information, and avoiding alarm fatigue are not well studied in literature" and are not well implemented in standard techniques
- This paper presents a method that allegedly requires "minimal training" and is good for tasks "requiring extreme precision."
- Two experiments allegedly show this method of sonification superior to standard methods.

Introduction

- Visual AR is rapidly progressing and proving useful in science, such as in medical professions
- "multisensory AR" would be even better, as you can track more variables, but doesn't currently exist in as good a form as visual AR
- Hearing sense is good to add because its "omnidirectional," and "gives a subject the capability to articulate the nuances of complex sonic environment"
- Background:
    - Sonification is gaining influence in science because of its pros
        - Vision already almost overloaded, so offload extra variables to sound

        - "Using auditory cues to indicate the occurrence of an event or conveying spatial or mechanical information has proven to be effective and reliable [11]."
    - Sonification and parameter mapping "is not directly comparable" to visualization
    - "alarm fatigue" – sensory overload "could lead to misinterpretation or loss of significant information"
    - Aesthetics improve work environment of users and bystanders/subjects
    - Intuitivity is good for making subconscious associations that help recognize stuffs
    - (citation) found pitch is most commonly used parameter
        - Most important variable to pure frequency
    - Conclusion that reference sounds are needed for an "interactive system"
    - "physical modeling sound synthesis" – generate sounds associated with known "natural phenomena"
        - Allows for more intuitivity
        - Decrease "cognitive load" and alarm fatigue.
- Previous Work
    - (citations) physical modeling has been done well by "Modalys" and [8], and captures the many sound aspects of an object
    - Shelly et al. experiment (citation) mapped curvature of an object to sound in a way that made intuitive connections even by non-experienced users
        - "physical modeling leads to less cognitive load" but still very understandable
    - Other studies (citation) show that physical modeling is feasible

Methods

- Vision isn't enough sensory input for some tasks like working under a microscope.
- "three sonification mechanisms are introduced that employ sound synthesized by physical modeling to embody touch, applied pressure and angle of approach in high precision tasks regardless of the sensing method"
- To sonify action/moment of "gently touching a surface," "recorded acceleration on impact is mapped directly into the sound volume and is inversely proportional to the elasticity of the virtual membrane"
    - Like sound of touching an egg yolk that jiggles
    - Inverse proportion done so that when slow+careful approach, don't miss low notes
- Pressure mapped to taps on wood/metal
    - As increasing to maximum pressure, time between taps becomes shorter and sound becomes more metallic
    - Soft threshold for "desired pressure" and "high but tolerable pressure"
    - Hard threshold for "maximum tolerated pressure"
    - "The difference between the soft threshold and the current applied pressure is inversely mapped to the sound volume as a guide to target" according to the function
        - $\mathrm{v}(\mathrm{c}) = \frac{\mathrm{c}^2-\mathrm{c}}{\mathrm{t}^2-\mathrm{t}}, \quad \mathrm{v}, \mathrm{c}, \mathrm{t} \in [0, 1]$
        - "v is the sound volume level of the playback device, c is the current pressure, and t is the soft threshold"

- Material of plate has input described by the function
  - $$\begin{cases} p(c) = \frac{m-w}{T}c + w & c \in [0,\ T] \\ p(c) = m & c \in (T,\ 1] \end{cases}$$
  - "T is the hard threshold, c is the current pressure, and $P(c)$ holds a value between w and m for wood and metal respectively which is then mapped to a vector of values responsible for the material the virtual plate is constructed from"
  - Not specific icons, but gradual shift
- Angle/pose mapped to frequency, based of "desired" angle/pose
  - Uses inverse squares, and not continuous, because this annoys and distracts the user less, alleviating some of the cognitive load while still guiding
- Many mathematical models for sound synthesis, this experiment uses the one of Modalys for aesthetics

Experiments

- Designed to compare "environments that are augmented only visually, solely aurally or with both techniques simultaneously"
- Desire high precision
- Error measures recorded separately
- Task 1
  - "use a digital stylus on a digitizer board…to track a moving object [(a circle, which moves with random direction and speed)] while keeping the pressure applied by the stylus at a target value that changes over time"
  - 3 feedback systems
    - Above sonification system
    - Visual color gauge on side with target and current pressure
    - Both feedbacks given
  - 6 Mock trials then real data collection
- Task 2
  - "Test subjects are asked to move a needle with a diameter of $0.3mm$ towards a transparent and highly viscous liquid and gently touch it while maintaining a certain angle" "under the surgical microscope while looking through the ocular lenses."
  - OCT image of needle and liquid, "computer vison techniques" to show angle, distance, etc., passed on 3 ways
    - "the OCT image and the target angle line are rendered onto a Heads-Up Display (HUD)" that can be seen through the lens of the microscope
    - HUD only shows "raw OCT", "angle and touch" sonified using the "proposed sonification method"
    - Both feedback given
  - 2 trial runs
  - Testers need to press a pedal every time they touch the surface, and keep at specified angle

Results

- Task 1
  - Best was pure sonification, worst was pure visualization, both in the middle for tracking the circle
  - For pressure, avg % error is 1.73 for pure visualization, 2.04 for sonification, and 1.69 for both; stdev same for sonification and both, higher for pure visualizaition
- Task 2
  - Accuracy for angle was avg 5.06 degrees off for pure visualization, 4.31 off for pure sonification, 4.64 off for both
  - For knowing when liquid was a touch, pure sonification and both were equally better than pure visualization

Discussion

- Improved accuracy when some visual information substituted for sound, though having both still helps
  - Sonification means you don't have to restrict field of view
  - Also, sound comes from everywhere, so you don't have worry about tracking errors
- In task 2, subjects had no training which explains why they were generally bad
  - Method of physical modeling allows natural associations which make it more intuitive
    - Having instrument change rather than just pitch change means less training needed
  - Having both visual and audial feedback doesn't take anything away, but does give some improvement in accuracy
  - Excuses given
  - Overall, "both experiments show feasibility" of the methods they used.

Conclusion

- Contributed model to follow
- Aimed to use "physical sound synthesis" for feedback, and thus improve accuracy in "high precision tasks"
- Restating intro
- Results show effectiveness of methods
- Future directions: feedback for tasks which "require[e] rapid reactions", generally improving current systems
- Real world testing is useful+important

Questions/Other

Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display

Source citation

Barrett, N. (2016). Interactive Spatial Sonification of Multidimensional Data for Composition and Auditory Display. *Computer Music Journal* 40(2), 47-69. The MIT Press. Retrieved September 16, 2018, from Project MUSE database.

https://muse-jhu-edu.ezproxy.wpi.edu/article/620161

Source type

Journal Article

Keywords

spatial sonification of multidimensional data, spatial sound synthesis, parameter-mapping sonification, interactive, minimal training, ambisonics

Summary

- Interactive and integrated approach to spatial sonification design
    - Interaction between time and space
- Being able to move in space in relation to data lets people see things they couldn't otherwise
- Considers aesthetics
- Combining many previous techniques into his
- "higher-level construction showing the interdependence of data, sound, interaction, aesthetics, science, and music"
- Can be used for science or art, small or big scale data
- Future application: creating "test material" and studying "geological faulting" and art composition
- Future expansion: adding sample outputs, recording function

Reason for Interest

This paper presents a method of sonification similar to something I was planning on building, an easy to use app.

Notes

Abstract

- This paper presents a new approach to modeling multi-dimensional data.
- The approach employs parameter-mapping sonification
- "Implemented in an" interactive "application called Cheddar", coded in "Max/MSP"
- "User can modify" sound and space parameters in real-time
- "Draws on existing literature" and author's background, but new and improved
- "Spatial information is sonified in high-order 3-D ambisonics, where the user can interactively move the virtual listening position" to gain better insight to the data, unlike previous applications. Generally high-def/high-tech
- Easy to use and requires "no specialized knowledge of programming, acoustics, or psychoacoustics"
- Allegedly bridges the gap "between science and art" to allow for more flow between the two disciplines

Introduction

- "Sonification in 3d space" allows for a useful way to interpret scientific data
    - The 3d allows for different perspectives
- Sonification is already used for various fields such as navigation and interpreting brain data (citations in paper)
- "Spatial elements [in music] have historically been a compositional concern" and were generally used to create an immersive and rich experience
- Sonification can somewhat fix this problem, and take "the focus" away from "visual impressions"
- In general, artists care more about aesthetics in sonification, while scientists care more about accuracy and precision, but it's a blurry line
    - Aesthetics can be useful to be able to listen to long tracks
    - Accuracy is good for sonification to reflect data
    - Interactivity of a sonification program allows the user to prioritize what they want
- This article presents the author's work on the application Cheddar, which interactively sonicates data
- The work "draw[s] on spectromorphological conceptualizations of sound and spatial behavior," various previous (cited) work on sound and sonification, and "how intrinsic features…and intrinsic features…interact"
- The app has undergone extensive development and presentation and reworking by the author
- First part of the article shows "underlying research and the design choices" of the app, and the second part "specific application of these choices in Cheddar" and then conclusion presents "practical applications" of the app.

Underlying Research and Design Choices

- "begin[s] by investigat[ion]" of "sonification techniques and" relevant data sets
- Then how we perceive "auditory space" and "a discussion" of past sonification programs that "display spatial differences" and their "practical applications"
- Then role of "aesthetics" and "practical considerations" in design
- Sonification Options and Data Sources
    - Four main sonification techniques (cited from *The Sonification Handbook*)
- <<□ 1 . Audification, described in Chapter 12 of *The Handbook*. This is a method that interprets a data sequence directly as an audio waveform.
- □ 2. Parameter mapping, described in Chapter 15. Changes in the sound are mapped from the data.
- □ 3. Stream-based sonification—features emerge through stream-based gestalts, similar to parameter mapping and, likewise, described in Chapter 15.
- □ 4. Model-based sonification, described in Chapter 16. Data are turned into dynamic models that the user "excites" to explore data structures via the acoustic feedback. ≫
    - "collaborations with scientists provided useful insights into the challenges of spatial data"
        - For example, data from "geological rock mechanics" was discrete but "sizable," which could make it challenging to have real-time sonification
        - There was problems with result not being heard, so "filtering data", "different types of sound input", "data reduction", and "manipulating the temporal duration" were considered.

  - Continuous trajectories through space could be mapped to time, and work well with parameter-mapping, but this gives only one locational look at the data
  - Cheddar was designed to handle wide ranges of data, and to be modular
    - Handles “six variables at any one time” and turns into sound
    - Processing power determines how many data sets can be sonified at the same time
  - Paper identifies a competitor, “SonEnvir,” which is modular, but requires programming knowledge and “limited” “real-time interaction”
    - De Campo made a design map which is based off of “the number of data points” (x-axis), “the number of properties of interest for each data point” (y-axis), and “the number of streams estimated to be suitable for meaningful data representation” (z-axis)
    - This data map was used to determine how to sonify the data
      - For example, density of data can be adjusted to make sonifications more audible or distinguishable.
      - The data map also allows for continuous adjustment of “data rate, data reduction, and a number of other parameters,” and means tempo doesn’t have to be initially decided
      - This data map can help the program and subsequently the user better interpret the data
- Direction, Distance, and Polyphony
  - Localization blur of sound gives angle (direction), and ears blur sound location
  - Moving through the “spatial scene” clarifies some ambiguities caused by ^^
  - Distance hard to detect with sound (though we’re better at gauging relative distances), so not processor prioritized
  - Drawing on previous (cited) work
- Previous Applications of Spatialization in Sonification
  - “Vector-based amplitude panning” (VBAP) is done with 3 speakers in space
  - “higher-order ambisonics (HOA)…captures…3-D sound in spherical harmonics describing the sound field” then converts it to sound file
  - “Wave field synthesis (WFS)…synthesizes the wave fronts of virtual spatial sounds by using a large number of individually driven speakers, based on the principle that the wave front can be regarded as a superposition of elementary spherical waves, but WFS has not be applied to any extent in sonification”
  - Cited application examples, but each don’t have enough interactivity
  - Cheddar used HOA
- Aesthetic Discussions on Sound Design
  - “casual mappings” – mappings where sound ← action related to it
    - More natural than “arbitrary mappings”
    - Natural → more aesthetic and recognizable
    - Seemingly small changes can make a natural sound unnatural
  - Repetition can cause problems
  - Organization makes sonification aesthetic and comprehensible
  - Imitation can make sonification more logical, but accuracy needs to be considered, especially in science
    - Science usually more abstract

  - Emmerson's "language grid" is a tool to connect sonification for science and art
- Interaction, Interface, and Program Design Options
  - simple interface, real time access to parameters is hard but ideal
  - controller

Cheddar (section)

- "six variables: 3-D spatial data, two free-choice variables, and either a fixed or a data-defined variable time step"

Table 1. Cheddar's Main Features

SONIFICATION METHOD
Parameter-mapping sonification Sound and space as information carriers Interactive and real-time auditory display One application useful for music and science

SOUND

A selection of presampled sound inputs or user created sounds
A selection of test signals (saw tooth, sine wave and filtered noise)
Granular approach: a sound or sound section is triggered for each data point
Grain transformations:
    Attack and decay amplitude envelope
    Duration
    Pitch transposition
    Volume
    Band-pass filter center frequency (for noise inputs)
    Attack enhancement
    Equal-loudness compensation (50-phon contour)
Individual processing for each sound grain for all transformation parameters
A density of up to 14 overlapping grains per data set
Simultaneous processing of multiple data sets
Spatialization encoded in high-order ambisonics
Spatialization decoded to any loudspeaker array or to binaural sound

INPUT DATA
Discrete-event time-series data sets containing up to six variables per data set Up to 1msec timing accuracy Data loaded as files or streamed in real-time from an external source Data filtering to focus on selected values (high-, low-, band-pass) Automatic detection and real-time update of data ranges passed to the mapping stage Modular design to tailor Cheddar for different computer speeds

MAPPING
Data is read at a user-defined time step or as a variable specified by each data point Unique sound can be allocated for each data set Three variables control spatial location of the sound grain Any data variable can be mapped to pitch transposition, band filter or to signal frequency Any data variable can be mapped to volume, sound grain duration, or attack slope

REAL-TIME CONTROL
Sound transformation scaling ranges Data rate for preloaded data files Data decimation Spatial listening location Spatial rotation transformations Data event range passed to the sonification Reverberation level All scaling parameters simultaneously transformable using MIDI faders

- "listening location" changes volume and reverberation
- Testing and Application
  - To create associations, they made sonifications of physical gestures
  - "space–time relationships are a key factor in gestural expression"
  - listening location matters

Questions/Other

A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities

Source citation

Dubus, G., & Bresin, R. (n.d.). A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities.(Research Article). PLoS ONE, 8(12), e82491. doi:10.1371/journal.pone.0082491

Source type

Journal Article

Keywords

Review, Sonification Techniques

Summary

See Abstract

Reason for Interest

This will help me gain background knowledge of how to implement sonification, and can also serve as a reference.

Notes

Abstract

- Serves to organize and summarize sonification techniques in experiments.
- Get trends and help future sonification design
- “list of conceptual dimensions” and “frequency of use”
- pitch is most used, “spatial auditory dimensions” are used for “kinematic quantities”
- not many paper evaluate “sonification mappings”
- Ends with proposing ”a mapping-based approach for characterizing sonification”

Introduction

- Overview of 179 publications “in order to identify established methods and techniques.”
- auditory dimensions - “psychophysical and physical dimensions of the resulting sound”
- Section 1: “concept of sonification
- Section 2: “systematic review”
- Section 3: building database and “extracting data”
- Section 4: “brief description” of sixty projects
- Section 5: Analysis
- then suggests future work
- Nature of Sonification
    - “(International Conference on Auditory Display – ICAD) was founded in 1992”
    - development of definitions
        - Gray and debated boundaries
- Character
    - Good for interpreting data, kinesthesia, “sensory substitution”
    - Quotes *The Sonification Handbook*, parameter-mapping is most-common used method
    - Model based sonification – like physical modeling discussed in other papers, “virtual sounding object”

        - Seems preferred
- Historical perspective
    - Mesopotamians used audition to "detect anomalies in accounts of commodities"
    - Many throughout history
    - Stethoscope, Geigner counter (for measuring radiation)
    - More recent explosion

(from the end)

Conclusions and Perspectives

- First made database of 739 entries, then randomly selected 60 project ("179 scientific publications")
- Analyzed things like "level of synthesis, the nature of the sound, and the software platform used"
- List of "conceptual dimensions" and "auditory dimensions"
- Restates abstract
- Results also supported the "hypothesis: the most popular mappings follow the logic of ecological perception."
- For future sonification projects or sonification research, one should consider these most-common approaches of parameter-mapping, pitch and/or "natural perception"
- Characterization of sonification via mappings
    - "all works that were included contain at least one description of a sonification mapping from a physical dimension to an auditory dimension"
    - "various specificities of the nature of sonification…can be expressed…by imposing restrictions on the domain and on the codomain" "of mappings"
    - Future characterization could be based off mappings technique

(back to section 2)

Motivations

- Organize current research which will serve as a reference for future sonification projects
    - Identify common techniques and trends
- Lots of citations of preview overviews
- When domain and range can be ordered, "the mapping is said to have a polarity if [it] is monotonic
- A previous database of mappings "was meant to organize sonification mappings according to three design components: nature, polarity, and scaling of the mapping"
- "pbysical" domains make mapping nice, so that's what is studied here

Methods

- Lists databases
- Focused only on "physical quantities"
- "intermediate-level dimensions" were grouped, like density of people or saturation of chemical
- Focused on "perceptual effects rather than sound synthesis techniques"
- "best solution is probably to have a multi-level and multi-scale structure for the classification of both physical and auditory dimensions

Presentation of Data

- 179 articles in paper, others online

- 33 physical dimensions, which "are distributed over five high-level categories: kinematics, kinetics, matter, time, and dimensions (table)
- 30 auditory dimensions, which "are distributed over five high-level categories: Pitch-related, Timbral, Loudness-related, Spatial, and Temporal (table)
- Table later summarizes 60 projects
- "multiple occurrences" of similar "low-level dimensions" are counted as same

Results and Discussion

- "principal measure considered…is the frequency of use of mappings"
- Preliminary hypotheses based on analysis of some articles:
    - "A large proportion of sonification mappings follow the logic of ecological perception."
        - "natural perception"
    - Pitch is "most used auditory dimension"
    - "Spatial auditory dimensions are almost exclusively used to sonify kinematic physical quantities."
- BIG Table in article (many pages, summarizes 60 projects)
- Data supports hypotheses (1 and 3 in 5.1.2)
    - One example of type of mapping that doesn't support or contradict H1
- 5.1.3 (supporting H2)
    - Found part-whole ratio of auditory dimensions, then "We performed pairwise Student's t-tests"
- 5.1.4
    - In the "category Kinematics: Pitch-related and Temporal auditory dimensions were found to be used significantly more often than Loudness-related auditory dimensions"
    - In the "category Kinetics: Spatial auditory dimensions were found to be used significantly less often than [other] auditory dimensions"
    - t-tests

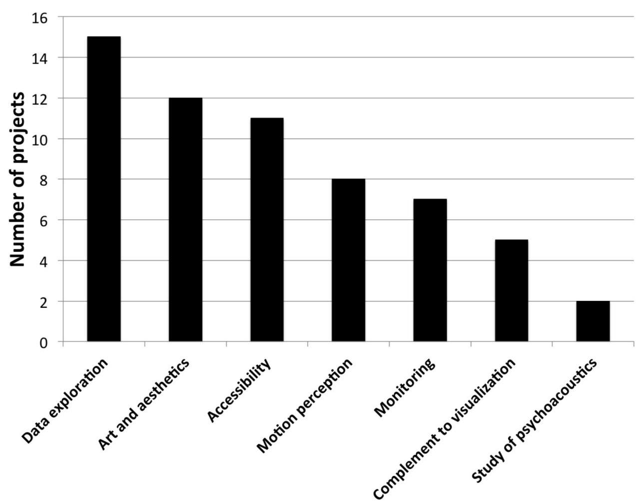
Table 7. High-level trends in the distribution of mapping occurrences.

	Pitch-related		Loudness-related		Temporal		Timbral		Spatial	
	N_m	%	N_m	%	N_m	%	N_m	%	N_m	%
Kinematics	64	26.8	30	12.6	53	22.2	45	18.8	47	19.7
Kinetics	19	22.4	24	28.2	19	22.4	19	22.4	4	4.7
Matter	22	29.3	11	14.7	19	25.3	23	30.7	0	0.0
Time	17	25.0	8	11.8	17	25.0	24	35.3	2	2.9
Dimensions	20	32.3	6	9.7	15	24.2	18	29.0	3	4.8

Distribution of mapping occurrences aggregated in high-level categories for both physical and auditory domains. The number of mapping occurrences identified is

-
    - "normalized the number of mapping occurrences in each high-level category in the physical domain against the total number of mapping occurrences"
    - Note on how time is more used than shown in results, as they didn't count instantaneous to instantaneous
- 5.1.5
    - Table of intermediate-level dimension data
- 5.1.8

    - Possible whole: evaluation of sonification projects is holistic, so it doesn't help fix the individual details, and evaluation is not standard, choice is sort of arbitrary
    - Assesment of good vs bad mappings in study (possible whole to improve)
- Some mappings weren't actually implemented in projects, marked by this study with an F.



    - This only looks at primary objective
    - Seems to be room for work in study of psychoacoustics with sonification, though study states this could be due to incomplete data set
- "The most popular ['synthesis tools'] were SuperCollider and PureData."

Questions/Other

The Sonification Handbook

Source citation

(Hermann, 2011)

Hermann, T., Hunt, A., & Neuhoff, J. G. (2011). *The Sonification Handbook*. Berlin: Logos Verlag.

Source type

book

Keywords

sonification

Summary

Reason for Interest

This book provides a good background on sonification, and is also good reference material.

Notes

See General Background.

Questions/Other

Fractal Music : The Mathematics Behind "Techno" Music

Source citation

(Padula, 2005)

Source type

Article

Keywords

Fractal, music, mathematics, Fourier Series

Summary

See Abstract

Reason for Interest

This is an easily accessible source (written by a teacher for teachers) which will help me understand some of the mathematics necessary for my project.

Notes

Abstract/Introduction/First section

- Article discusses The Fractal equation, Fourier's theorem, sound waves and "their basis in the sine curve" and algorithms to compose fractal music
- Visual fractals are self-similar and cool, they can be translated into numbers and equations which are in turn translated into music
    - Fractal coordinates can come from feeding a complex equation's result back into itself

Physics of Sound Waves

- sound waves are pressure waves, composed of infinite sum of sine waves

Fourier analysis/Fourier's theorem

- Fourier analysis is a way to analyze sound, backed by Fourier's theorem
    - Fourier's theorem says any waveform with period n can be expressed as an infinite sum of sine waves with frequencies that are integer multiples of the waveform's frequency*2π
    - The original/first frequency is called the fundamental frequency or first harmonic, corresponds to pitch
- Chaos theory is concerned with phenomena that are influenced in a large way by tiny differences
    - Equations arising from chaos theory were also used to produce fractal music

Fractal Music on the Internet

- References www.geocities.com/SiliconValley/Haven/4386
- Lorenz examined weather phenomena and found that small changes in places farther than the fifth decimal place can be important and cause changes, and this gave rise to chaos theory
    - His equations were explored musically by Diaz-Jerez on the website

Lorenz (CD Fractal Sounds – Volume 1)

- equations give x, y, z, coordinates which are then mapped to sound

Lorenz attractor

- The equation that gave the x, y, z coordinates came from seeming chaos, but had underlying structure

Lorenz attractor exists – an interesting proof

- Since equations are so sensitive and computers can’t handle infinitely many decimals, mathematicians want proof (cited solution) that outputs of Lorenz attractor equations actually give orderly shape, and its not a symptom of rounding

Students and Techno

- FractMus and Musinum allow students make own fractal music

Integrated Curriculum Aspects

- music is useful for motivating students to be interested in math
- Largely irrelevant

Aesthetics

- Mathematical music isn’t necessarily good music, but can be
    - Some composers have been working with fractal music, while some use it as a basis for musical pieces

Questions/Other

`Curve Shape and Curvature Perception Through Interactive Sonification

Source citation

(Alonso-Arevalo et al., 2012)

Alonso-Arevalo, M. A., Shelley, S., Hermes, D., Hollowood, J., Pettitt, M., Sharples, S., & Kohlrausch, A. (2012). Curve shape and curvature perception through interactive sonification. *ACM Transactions on Applied Perception, 9*(4), 1-19. doi:10.1145/2355598.2355600

Source type

Journal Article

Keywords

Curvature, interactive sonification

Summary

See Abstract

Reason for Interest

This article should help me get a feel for sonifying mathematical qualities, and I may use a similar sonification strategy to the one presented

Notes

Abstract

- approach that "uses sound to communicate geometrical data related to a virtual object"
    - Specifically surface of the object (from intro)
- Interface lets user "evaluate the quality of a 3D shape using touch, vision, and sound."
- many strategies to map "geometrical data…into sound"
- fundamental frequency used for "curve shape" or "curvature"
- two experiments, one with participants with "varied background," and other group had "a background in industrial design."
    - Success

Introduction

- CAD tools used in designing stage to prevent need of many models
    - However, seen on 2-D monitor and only interaction is (usually) through mouse and keyboard
- "SATIN project" – superset of this study – aims to develop augmented reality interface where users can "explore and modify" 3-D objects directly with touch
    - Sound will be one of the feedback devices, can be used to show "geometric properties related to the surface" which are hard to get from "touch or sight"
    - Existing whole in "the possible role of auditory modality"
- Shape and Curvature need to be sonified per the SATIN project
    - Important for aesthetics
        - E.g., continuous surface is prettier due to how light reflects off of it

SATIN System Description

- Visual Interface
    - Projector and 3-D glasses, glasses have a sensor for location, when touching haptic interface have illusion of touching visual object
- Haptic Interface
    - Cutting plane – 2-D cross section of object that is interacted with via the haptic interface

  - haptic strip – flexible strip that can morph into shapes, with limitations
    - Ends of strip allow adjustment of cutting plane, strip is sort of like a touch pad
- Only one currently built SATIN system, not portable, expensive
  - Researchers used a tablet and stylus to mimic haptic interface
    - Allowed for pressure sensitivity

Related Work And Background

- Previous studies (cited) show that sonification of images, higher-dimensional data, and surface data has been done successfully
- Other studies have done sections of this study's goal in other contexts
  - Interesting one to look at might be MANSUR, D. L., BLATTNER, M. M.,AND JOY, K. I. 1985. Sound graphs: A numerical data analysis method for the blind. J. Medical Syst. 9, 163–174.
- Previous research has developed "sonification toolkits" which allow for general sonification, but require "predefined data sets"
  - The toolkit I am (probably) using was mentioned

Sonification of Geometrical Data

- System will let user know about curve shape or curvature (prechosen which one) at "point of contact" of a geometrical object
- Curve shape is a plane curve from the cutting plane
- Curvature is reciprocal of radius of osculating circle, for function C=f(q) equation is
  - $\dfrac{\frac{d^2C}{dq^2}}{\left(1+\left(\frac{dC}{dq}\right)^2\right)^{\frac{3}{2}}}$
  - They use porcupine method (irrelevant knowledge)
- Mapping Data to Sound
  - Other studies have explored "best" way, find intuitive one makes everything easier
  - testing with experts led to the decision to map parameter of interest mapped to frequency
  - Linear changes mapped to logarithmic changes in sound
  - "kinetic module" "postprocesses generated sound" to allow intuitive relationship between interaction method and sound

Carrier Sounds and Kinetic Module

- Sounds carriers were Sinusoidal carrier, Wavetable Sampling Carrier, Physical Modeling Carrier
  - Each method of generating sound is mathematically intense, but ultimately they work to generate a note that sounds like a specific instrument or physical phenomenon and change the fundamental frequency as needed by input
- Kinetic module makes sound feedback more intuitive by postprocessing what would be played to the user
  - Previous (cited) study shows that wider range of "spectral slope" and frequencies require less effort to understand
  - Varies sound according to mathy equations and techniques to make it fit into an intuitive range of volume and pitch and sound harmonics

  - Not much use for sinusoidal carrier because its already so simplistic, so no complexities to be adjusted

Evaluation and Results

- 2 studies, one as previously described with tablet in UK, one in Italy with actual SATIN "setup and interface"
- First study
  - Allowed to explore curves on a tablet and hear sonification, then asked to pick out of four options the right curve corresponding to sonification
  - 75 total questions in random order, 15 in each of 5 sonification categories
  - two sessions, one for curve shape one for curvature, on different days
  - Measured accuracy and response time, and asked participants what sonification technique the preferred
    - Most preferred was "wavetable sampling carrier" (sounds like a cello)
  - No significant differences found between groups neither by curvature vs curve shape or by sonification technique (not even when adding the kinetic module)
    - Reveals probably fundamental frequency is what matters
    - Dedicated studies are probably better for determining whether or not it is useful to have sounds be intuitive
  - Kinetic module was supposed to help by making feedback more natural, which would help the brain process it better due to (cited) neurological processes
- Second study
  - Expert participants explored a vacuum cleaner using SATIN with sonification and had to determine minimum, maximum curvature and points of inflection
  - Stereo with one side positive curvature, one side negative
  - Questionnaire with many questions, participants found sound help them find un-seeable parts of curve shape and curvature, but was annoying and "not comfortable" "for long periods of time"
- Generally good results for both studies (from tables

Discussion and Conclusion

- Generally successful
- Restates earlier information
- Participants found mapping to frequency may be irritating if done for a long time
- Restates more info

Questions/Other

TESTING THE EFFECTIVENESS OF SONIFIED GRAPHS FOR EDUCATION: A PROGRAMMATIC RESEARCH PROJECT

Source citation

Bonebright, T. L., Nees, M. A., Connerley, T. T., & McCain, G. R. (2001). Testing the effectiveness of sonified graphs for education: A programmatic research project. Georgia Institute of Technology. ---From Google Scholar

Source type

"Proceedings of the 2001 International Conference on Auditory Display, Espoo, Finland, July 29-August 1, 2001"

Journal Article?

Keywords

Education, Sonification, sonified graphs, gra

Summary

See Abstract

Reason for Interest

This source should help me develop my idea for testing the use of sonification in education, as it is similar to what I want to do

Notes

Abstract

- "Builds on results from sonification of data" and "comprehension of visual graphs"
- Do "sonified graphs" increase student "comprehension of graphed data"
- Are "stereo or monaural sonifications are most effective for graph comprehension" ?
- Do "sonified graphs with rhythm markers result in better comprehension than sonified graphs without them" ?
- Three experiments:
- "can [students] match auditory representations with the correct visual graphs"
- "can [they] comprehend graphed data sets more effectively by adding sonified components"?
- "can [they] be trained to use sonified graphs better with practice"
- "Results could" lead to new teaching practices and "teaching students with visual impairments"

Introduction

- Lots of research on visual graph comprehension, sonified graph comprehension research "is in its infancy"
  - Note to self, this is from 2001
- Some research on comprehension of certain graphs presented sonically, but "little research…investigating using sound in addition to visual displays in education"
- "project consists of three studies:
- matching visual and sonified graphs;
- comparing comprehension of visual and sonified graphs,
- …practicing the use of visual and sonified graphs"
- "emphasis on real data sets from" many "disciplines"

- Restates abstract

Study 1 – Matching Visual and Sonified Graphs

- "Results demonstrate" how intuitive "underlying assumptions" of sonifying graphs are to students and "how performance varies for stereo and monaural graphs"
- Participants
    - o "54 college students with normal vision and hearing"
    - o range 19 to 23, "mean age of 19.5"
    - o 3 excluded because thought to be "not taking the task seriously" (everything wrong)
- Stimuli
    - o "Real data sets" "taken from DASL" "were graphed using CricketGraphic and sonified using Metasynth and SoundEdit software packages."
    - o "both bivariate and multivariate data sets"
        - ▪ Bivariate sonified using flute voice, multivariate using flute and bassoon, all data fell within three octaves
        - ▪ bivariate: x→time, y→frequency (monaural)
        - ▪ Multivariate: """""""""" (binaural), frequencies in different ear
- Procedure
    - o "3 practice trials" with "simplified graphs" then "24 test trials"
    - o presented participants with sound then given 4 visuals, had to match the graph
    - o Could repeat the sound, told to prioritize accuracy but also work quickly
- Results and Conclusions
    - o "independent variable" "for the main analysis" was binaural or monaural sonification
    - o "dependent variables collected included number of correct matches, reaction time for each choice, and number of times the sonified graphs were played"
    - o "Participants were asked about" musical background, but this did not end up distinguishing groups
    - o On average good results, mean of 42.3/51 correct matches for all graphs.
    - o Hardest graphs to identify were 10 and 17, and they had a wide dispersion "and lacked a definite shape for the data"
        - ▪ "confused most often with other" graphs with similarly "widely dispersed data points and no easily discernable 'envelope'"
    - o Based on stats given, mono graph matching was quicker, took less plays, and was more accurate than matching stereo graphs
        - ▪ Bivariate easier to match with their mono than Multivariate with their stereo
    - o Generally, students had good graph matching, so this study means future research can expect people to match sonifications to visual graphs

Study 2 – Comparing Comprehension of Visual and Sonified Graphs

- "designed to assess comprehension of information presented in graphed data sets comparing visual graphs with two types of sonified graphs"
- "one type of graph is the same as was used in the previous study while the second type adds a rhythm component" for x-axis
    - o "auditory referent for the listener"
- Varying levels of difficulty

- Participants
  - Similar sample
  - 3 groups: visual only, visual + sonification, visual + sonification + "rhythm markers"
- Stimuli
  - Similar to before, for rhythm markers have "a synthesized snare drum) that indicates the tick marks on the x-axis"
  - 28 graphs, 7 line bivariate, 7 scatter bivariate, 7 line multivariate, 7 scatter multivariate
  - Before seeing graph participants were given context/description
  - Then 4 questions of "vary[ing]…level of cognitive complexity"
- Procedure
  - 1.5 hour session
  - Survey
  - 4 practice trials
  - 4 trials per graph, one for each question
  - total 112 questions, "two 2-min breaks during the session to reduce fatigue"
  - Survey with difficulty, "strategies used to understand the graphs," "usefulness of…sounds"
- Possible Results and Conclusions
  - dependent variables:
    - "number of correct responses to questions for each graphs type"
    - "number of correct responses for each question type"
    - "number of correct responses for bivariate and multivariate graphs"
  - Will take into account demographics and musical experience
  - Ongoing study

Study 3 – Practicing the Use of Visual and Sonified Graphs

- How well practice works
- Similar methods to study 2, but "repeated exposure to the graphs over a period of 6 weeks." Each person only does one type of feedback
- Stimuli
  - Same as Study 2
- Proposed Procedure
  - Similar to Study 2, but hour long sessions for 6 weeks
- Possible Results and Conclusions
  - Same as Study 2
  - Hopefully practice improves performance
    - Hypothesis that "change will be greater for the two conditions with sound, since the students would not have had previous exposure to such displays"

Conclusions

- Obvious goals stated earlier
- "testing using a longitudinal design" to see/hope that practice makes improvement
- Past work is usually "one-shot studies"
- Future work to "focus on working with younger children and students with visual impariments."

Questions/Other

The paper is from 2001, so current work on the studies should be finished, but I can't find it (I looked up the author on Research Gate). I am not sure if it was every finished?... If not, why not???

Towards Designing E-learning Materials Based on Multi Learner's Styles

Source citation

(Deeb & Hassan, 2011)

Deeb, B., & Hassan, Z. B. (2011). Towards Designing Elearning Materials based on Multi Learners Styles. *International Journal of Computer Applications, 26*(3), 7-10. doi:10.5120/3086-4225

Source type

Journal Article

Keywords

E-learning, learner's style(s)

Summary

See Abstract

Reason for Interest

This will help me learn about different learning styles

Notes

Abstract

- "each learner is provided at birth with a certain learning style specific to any of the three main ones, (Visual, Auditory and Kinesthetic)."
- "ideal learning style" is a varying mix
- Individual learning style is static combination (of possibly one) but not dynamic
- Goal to "prepare a courseware material that fits the dynamic learning needs of all learner styles"

Introduction

- Courses should be flexible to accommodate needs of variety of students
  - A goal of "adaptive e-learning systems" is to adjust material to be suitable to each learning style
- The (cited) learning style definition: "It is the way how learners perceive and process information in different way
  - Should recognize individual learning styles
- Many models, "one of the most important models is one" from Sarasin (cited), has "three preferred styles of learning"
  - Visual learners like to see teacher, facial expression, etc.
    - 5 Lessons to be analyzed are outlined, will be visual based
    - Teaching instruments should be visible, interactivity in drawing
  - Auditory learners learn through listening to discussions, etc.
    - Use pitch, speed, other aspects of sound in interpretation, so written word not as meaningful
    - Analyzed lessons include listening and speaking and acting
  - Kinesthetic learners learn by "touching, doing, and moving"
    - Hands-on and learn by exploring physical world
    - Analyzed lessons include experiment and activity types

Related Work

- "adaptive management system" supplements an e-learning system by "actively engaging learner in content interpretation"

- (cited) study showed existing focus "on Intelligent Tutoring System (ITS) and the Adaptive Hypermedia Systems (AHS)"
    - "General Teaching Community" makes it hard for adaptive e-learning "to become a main stream." Author wants integration with "e-learning tools and platforms"
- Existing "standard Moodle" (current e-learning system) doesn't treat individual learners differently
    - "Needs to be customized" to accommodate for Visual, Auditory, Kinesthetic learners
- Irrelevant (cited) study
- (cited) study showing why "improving the efficiency of learning through an e-learning environment, is due and challenging."
- Certain "VAK survey" used to asses learning style
    - "Proposed solution" aims to make lessons partially visual, auditory, and kinesthetic according to learner's needs instead of being only one, as most learners are a combination of VAK

Research Methodology

- Courseware will be combination of V, A, K styles based on multitude of learners
- Two stages: research existing literature, give survey that proves people are a combination of VAK to serve as a basis of how to design "courseware"
- Students given survey from Victoria Chislett, "a specialist in performance psychology," results were that some students have "strong inclination" to one style, some have mix of two styles, and (rarely) some have mix of all 3

Course Materials Design

- Material should be "presented in the three learning models" and "should be presented online in many different ways, including text, visual images, website links, video clips, audio clips, animation and flash."
- Lesson will have total of 5 Visual lessons, 5 Auditory, 5 Kinetic, but students will be given some of each (e.g. 2 visual, 1 auditory, 2 kinetic) according to the questionnaire
    - In old approaches there is a static combination

Proposed System Architecture

- largely irrelevant or redundant for my purposes

Conclusion

- VAK categories are useful, teachers should keep them in mind and teach all three kinds
- Future study will measure effectiveness of proposed system

Questions/Other

The future study might be an interesting read, but not completely necessary until the later stages of my product

SONIFICATION SANDBOX: A GRAPHICAL TOOLKIT FOR AUDITORY GRAPHS

Source citation

https://smartech.gatech.edu/handle/1853/50490 /
https://smartech.gatech.edu/handle/1853/50490?show=full

Source type

Article

Keywords

Sonification toolkit, auditory graphs

Summary

See Abstract

Reason for Interest

This is an article about a sonification software that seems like a viable option for my project

Notes

Abstract

- Java-based application that addresses need for a "multi-platform, multi-purpose toolkit for sonifying data"
- Users can "independently map several data sets to timbre, pitch, volume, and pan"
- Applications include assistive technology for blind people, education, data exploration, and experimentation with sonification

Introduction

- data is mapped to "parameters of a synthesized tone" "to create an 'auditory graph'"
- Current sonification software/applications are too niche and not widely accessible for usability or hardware reasons (or software dependencies)
- Need for software that everyday person can use

Related Work

- Built on previous work like MUSART, but focuses more on "addition of content" than focus "on addition of musical elements"
  - Also, MUSART written in "C++, Csound, Fltk, and OpenGL" but doesn't work for any platform
- Also works on top/after of Sound Grid, but more precise and "provide[s] auditory context"
- Most current literature have sonification solutions that are limited by "need for exotic hardware, support for very few platforms, domain-specific design, and limited numbers of data sets and/or parameters

Design

- "simple, user-friendly, moldable, responsive…one size fits all…open source"
- "easy sharing of auditory graphs across multiple platforms"
- Not as complex as other softwares
- Current Status
  - Stable version that can run on a platform with java
- Data Input
  - Can import from csv files which can be saved from excel workbooks
- Mappings
  - "each data set can be mapped to pitch, timbre, volume, and pan independently"

- Also option for default values
- Software does "linear transform" from original range to range specified by parameter max and minima
- ability to "reverse the polarity of a mapping"
- Only one data set mapped to time, which ends up being first available one entered
- "checks and balances" in place to prevent bugs
- context to act as tick marks can be added "in the form of a click track"
  - "Can be played at the mean, minimum, or maximum of a data set."

- Playback and Output
  - "standard Play/Stop/Pause…buttons", also "progress bar", loop and hold buttons as well
  - export as a midi file
- Work in Progress
  - "continues to evolve"
  - some mappings have positive polarity (quicker=louder) but some have negative polarities
  - Needs to be set up by a non-blind person, hopeful future addition of accessibility for the blind
  - Data editing spreadsheet in the application itself and ability to save projects; also have a visual graph
    - This exists in the version I am using

Conclusions

- Need for widely-accessible tools to implement results of experimental studies in sonification
- This software is a step towards this goal

Questions/Other

Make Listening Safe

Source citation

http://www.who.int/pbd/deafness/activities/MLS_Brochure_English_lowres_for_web.pdf

Source type

Keywords

Summary

Reason for Interest

Notes

Questions/Other

Example Document

Source citation

Source type

Keywords

Summary

Reason for Interest

Notes

Questions/Other