BOTSOT: A Generative Sonification Toolbox

Ciaran Frame
Sydney, Australia
www.ciaranframe.com
ciaranframe@gmail.com

Abstract

BOTSOT is the Botanical Sonification Toolbox – a series of generative sonic tools created to explore invisible communications, structures and information within plant species. Developed as a series of modular Max/MSP instruments, generative processes and a graphical user interface are used to reveal discrete, user-generated sonic representations, thus extending knowledge and understanding of botanical life – a world that is often only fully accessible to scientists. Through the use of data sets and quantifiable characteristics of any given plant species, BOTSOT allows for extended comparisons, iterative compositions and educational experiences, as well as extending knowledge on plants through the medium of music.

Sonification of data is not a new notion - sonic representations and the use of data in music extend back through a rich tradition of computer and acoustic music alike. This paper explores the methodologies and compositional frameworks used in BOTSOT, presenting a fresh theoretical approach to sonification and generative music. The paper demonstrates that this area of work is still one that requires greater attention in research and practice, providing a rationale behind codifying the natural environment into generative music tools. Using past examples of data sonification, the paper discusses the use of generative, reproducible processes and interactivity as a means of extending users' knowledge and understanding of botanical life, outlining the ways in which subjective interpretation and a curatorial approach to data sets may advance future work into generative music. Each 'module' of BOTSOT is described in detail, with justifications behind their development, as well as where their future may lie.

1. Introduction

BOTSOT is the Botanical Sonification Toolbox - a set of generative sonic tools designed to synthesise physical characteristics of a large array of plant species. Music in the form of rhythms, drones and melodies is generated through these tools, uniquely sonifying plant species using curated data to meaningfully represent any given plant. Tools operate as either standalone generative instruments or in conjunction with other tools, with each module possessing the ability to musically and functionally communicate with every other in the toolbox.

Figure 1 – Modules in BOTSOT

BOTSOT was created out of an impetus to increase botanical awareness, providing understanding and access to data often only accessible through the eyes of a botanist. Wandersee and Schussler point to the prevalence of "plant blindness" and "zoocentric" observations, particularly in applied sciences [1]. Their work describes how people habitually fail to notice plants in their environment, pointing to key factors of plants' chromatic and spatial homogeneity, static proximity and non-threatening nature. These concepts profoundly influenced the creation of this toolbox from a personal artistic perspective, building on my past work in bioart and providing natural creative momentum.

Through iterations and comparative works, BOTSOT has created a body of work derived from a unique interactive process that extracts information from plants, presenting botanical data as sonic information. Individual generative modules allow for interactivity and diverse sonic results, whilst still retaining an iterative, repeatable outcome that reveals unique sonic insights in the world of botany.

This paper explores a renewed approach to generative music, using interactive sonification as an algorithm for generating unique and informative sonic results. An outline of the discourse will reveal elements of model-based sonification that do not manifest themselves in similar toolboxes, with an exploration of guiding principles of BOTSOT illustrating how the software encourages a greater understanding of plants through generative processes. Finally, a summary of modules and examples of applications and outcomes of the toolbox is discussed.

2. Context

2.1 A Tradition of Sonification

Examples of sonification can be found throughout multiple fields of computer music. The same can be said for 'toolkits' and interactive sonification engines that provide a creative framework for generative music. Past examples of similar sonification frameworks include SoniPy, a Python framework for the collection and integration of sonification modules [2], and Monalisa, a plugin style tool that integrates with existing Digital Audio Workstations [3]. Of particular note is the more recent work of Marcus Maeder and Roman Zweifel, "Trees: An artistic-scientific observation system", which shares many similarities with BOTSOT, sonifying multiple data sources received from plant sensors through a surround sound installation [4].

In this paper, the "model-based sonification" definition proposed by Hermann is used to provide formal context and structure surrounding generative techniques [5]. Important features identified by Hermann (shown below) illuminate the key features of sonification technique on which BOTSOT builds.

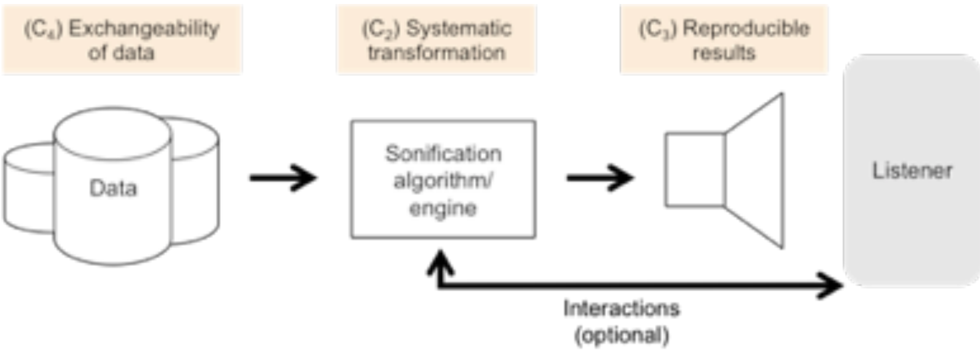

Figure 2 – The model-based sonification pathway

Expanding on this definition, BOTSOT seeks to bring fresh design principles and frameworks to sonification and generative music, with the use of human-computer interfaces and data that provides a new informative listening experience.

Supper has discussed the social context of sonification at the art-science boundary and how it perpetuates the notion of transformative listening experiences, stating "...producers and communicators of sonifications create the expectation that listening to a sonification yields a sublime experience…" [6]. BOTSOT relies on this precedent whilst also drawing from the context of practical auditory display [7]. In following sections, it will be asserted that new model-based sonification methodologies can generate music that facilitates elegant transformations of specific datasets and a heightened understanding of a given plant species.

2.2 Design Principles

In creating BOTSOT, a single core guiding principle drove the development of each generative instrument: how can any generative module capture the essence of a plant, and create a unique sonic signature that represents the plant in a way that may reveal information and characteristics previously lost to the phenomenon of plant blindness?

The existence of this broad goal necessitated the implementation of two key design principles, which would drive the creation of BOTSOT. These key principles would serve not only to differentiate the toolbox from preexisting generative tools, but also to create momentum for this style of generative music and the place it occupies within the arts and my broader community.

Through the lens of model-based sonification, BOTSOT modifies two key cornerstones of the traditional model through an altered data transformation pathway that distinguishes it from wide-ranging sonification methodologies that already exist, particularly in the area of bioart. They are:

1. The use of ‘curatic data’ tailored and edited from plant species specifically for the purposes of sonification
2. The use of a flexible human-computer interface, involving data navigation and excitatory interaction

In the context of the previously explored model, these additional parameters form a new framework for data sonification, as seen below.

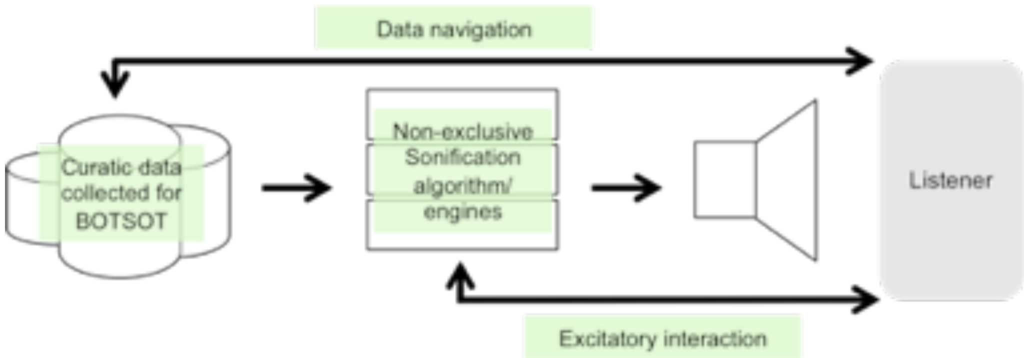

Figure 3 – The altered model-based sonification pathway

The end result is an extended sonic experience influenced by the user, whilst remaining inherently connected to the plant species, that stills allows for a generative experience consistent with more typical iterative model-based sonification processes.

3. Model-based Sonification

Within the framework of model-based sonification, each module in BOTSOT represents a single, non-exclusive “sound-capable object” [5]. The overall control of these modules differs from a standard sonification model through the aforementioned expanded process, outlined in greater detail below.

3.1 ‘Curatic’ data

Data used for the purposes of sonification has traditionally been extracted through traditional methodologies related to large, accessible file formats [8]. Unprecedented access to data from a large array of sources has led to the inception of open datasets and streaming API clients - what has typically been described by Kitchin amongst others as a “data revolution” [9].

Data used in BOTSOT has been collected in collaboration with the University of Sydney School of Life Sciences specifically for the toolbox. Data collection that is formally integrated into the process of sonification has allowed for a greater amount of control, notably in areas of quality control and module creation. Additionally, data that has been collected differs from traditional formats typically associated with generative music.

Within the field of music, an explosion of open data has afforded composers the ability to generate music with relative ease. At the intersection of botany and music, strong emphasis is placed on numerical and quantitative datasets that derive directly from primary measurements, seen through examination of three significant botanical sonification examples as in Table 1.

Table 1 – Examples of data formats in botanical sonification

Name	Data input
Trees: An artistic-scientific observaton system [4]	Daylight [RGB brightness] Solar radiation Sun position Air temperature Rel. air humidity Rain Wind Soil water potential Tree branch diameter Tree sap flow
sLowlife [10]	Seedling height over time Blue light exposure
MIDI Sprout [11]	Resistance circuit (integer threshold)

Quantitative data, particularly in the form of easily ingestible text files and sensor-based applications, is a preferential format for the majority of standard music tools and software such as Pure Data and Max [8]. Additionally, excitatory systems are less present in the discourse, and tend to focus on a single systematic transformation. BOTSOT differs in this regard, with data derived and translated from less traditional forms, including shapes, descriptions and images.

In line with attempting recovery of information previously lost to the phenomenon of plant blindness, the 'curatic' nature of data collection that has been undertaken creates a stronger sonic solution to specifically identified problems such as chromatic and spatial homogeneity in plants by fostering a measurement approach that is intrinsically linked to the sonification process. Additional data editing has also occurred to make data more immediately accessible for use in an interactive context. Examples of data used in BOTSOT are seen in Table 2.

Table 2 – Examples of data formats and editing in BOTSOT

Module	Data input	Data result
Shape Sequencer	Image of macro shape	Distribution matrix
Keyword Synth	Scientific description	Scientific description with associated keywords
DNA Sequencer	Full DNA Sequence	Trimmed DNA Sequence
Image Envelope Generator	Image	Vector outline

BOTSOT's 'ground-up' approach for all aspects of model-based sonification has determined that the process of forming generative tools and collecting data have occurred simultaneously, to the benefit of each. For instance, beginning with the objective of increasing awareness around physical structures in plants, it was concluded that a simple matrix would accurately represent a simple two-dimensional shape, and a MIDI sequencer that could read that shape would be able to systematically transform density and physical distribution into sound. An accelerated methodology for collecting this data through photography and simple image analysis was then engineered, allowing for the immediate testing and refinement of the data format, seen below.

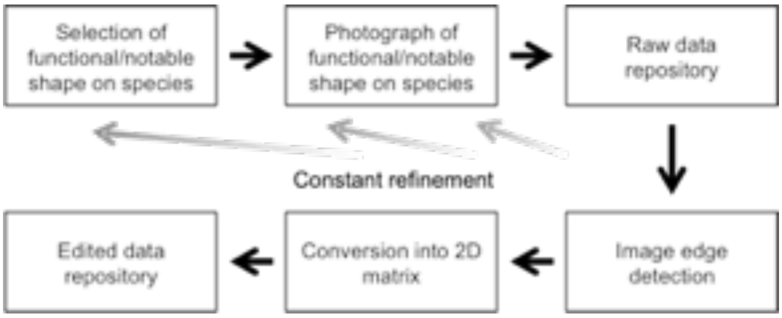

Figure 4 – Iterative data pathways in Shape Sequencer module

This curatorial collection of qualitative and quantitative data is rarely used in sonification, typically due to connotations of tarnishing the objective process of data representation [12]. To a certain extent, it would appear that a greater degree of data parsing and translation before sonification would produce a more abstracted and less systematic transformation of data into sound. On the contrary, the methodology surrounding data in BOTSOT has produced benefits of consistent control of data and easily adaptable methodologies, retaining the foundational requirements set out in Hermann's model-based sonification definition, namely systematic transformations of data and reproducible results. This approach bears the consequence of a lower quantity of data due to the labor-intensive, specific process.

3.2 The human-computer interface

Interactivity plays a key role in the generation of music in BOTSOT, with interpretation and generative processes undertaken by all users. BOTSOT uses the human-computer interface as part of model-based sonification in two distinct ways: for excitatory interaction and data navigation.

Modules in the toolbox are a series of dynamic processes, and it is the user who initiates sound generation. This style of generative music is typically associated with live performance (see for instance [13]). In the case of BOTSOT, the excitation of generative systems also includes the ability to change the systems themselves, that is, the systematic transformation of data into sound may involve any combination of systems. This feature allows for a greater amount of user control, and encourages unique creative processes that bring about a greater connection with the data and information surrounding any given species of plant.

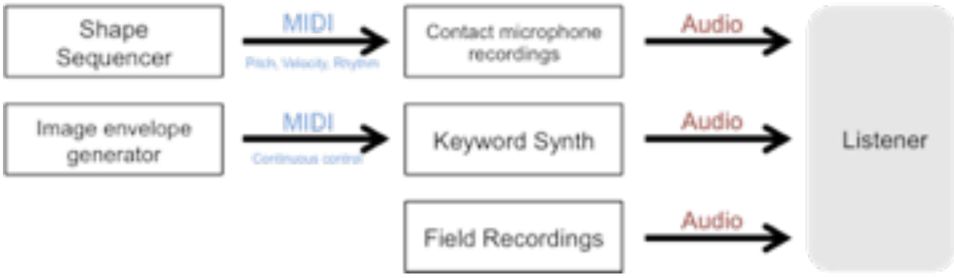

Figure 5 – Example of use of non-mutually exclusive modules in BOTSOT

Additionally, modules in BOTSOT also afford the user the ability to navigate the data itself. User interaction has been proven to be a constructive method for fast interpretation of datasets of larger bandwidths [8], however, data is often sonified on an 'as-is' basis with user interaction maintaining focus on systematic transformations of data into sound. For example, in the case of [4], all data sources are excited simultaneously for sonification, with temporal movement remaining constant. Interaction and navigation with data from the user is a consistent feature of all BOTSOT modules, with the user able to select various datasets and decide on specific species of plant they desire to make music from. This seamless interface with data naturally gives rise to iterative processes and comparison, allowing for extended subjective experiences and thus a greater ability to personally and creatively reflect on plant species.

Within this framework, both interpretation and interactivity are inseparable. Work from figures such as Manovich has often targeted the subjective and interactive aspects of data representation, arguing that scientists and designers already 'map' data in ways that are aimed at understanding [14]. Thus, counterintuitively, for the reasons outlined above BOTSOT does not produce 'one sound' for any given plant species. However, the presence of systematic generative processes from data into sound determines that every plant input still provides a unique sound signature, and interactive but consistent processes, affording the user the ability to create musical variations in pitch, rhythm and tone colour even within discrete systems.

4. Realisation

4.1 Max

BOTSOT has been created exclusively in Max in order to allow for an accessible user interface that has the greatest potential for expansion and efficient adaptation in the future. Behind each module is the generation of exclusively MIDI or audio information. This was deemed important as it not only allows for inter-patch communication, but also communication with other pieces of software - a feature greatly enhanced by Max's flexible patching environment.

An accessible user interface remained a priority throughout development of BOTSOT. All patches include help files (accessed through the top right corner of every patch) that explain basic functions and processes. As well as this, all internals of patches are labeled with comments if the user seeks further understanding of the inner construction of the module and how data is transformed. Users can control the flow of MIDI information from the locked patch, but are also invited to unlock patches and take advantage of Max's powerful MIDI transformation capabilities. For more advanced users, the unlocked patch also contains a detailed MIDI control engine.

4.2 Data storage and exchange

BOTSOT in its entirety is stored in a Github repository under an MIT license, providing open access to all users. Users are directed through a simple readme file, with all required sonification data being stored within subfolders. Referencing is controlled automatically through the Max patching environment with central .coll files (marked in patches) that direct the module to additional resources, such as text files of DNA data, help patches, and images.

For data navigation, all modules contain the same 'plant selection engine', seen below.

Figure 6 – Plant selection engine

Different plants can be loaded into the selection engine depending availability of data, with the number of plants available constantly expanding. For backend data management and parsing, Python has been used, in particular Scikit and Numpy.

5. Modules

5.1 Shape Sequencer

The Shape Sequencer is a simple note-generating system that operates as a form of extension to the traditional MIDI sequencer. It takes a characteristic botanical structure from a given plant species (such as a flower spike from the *Banksia aemula*), and translates the shape into pitch, rhythm and velocity. A focus on discrete macro shapes and their relation to sound is a methodology useful for reducing the effect of seeing plants as spatially homogenous.

The sequencer uses a large matrix of pixels based on a graphic representation of any structure in order to trigger MIDI notes. A slider moves vertically through the matrix, crossing randomly selected points within the shape that trigger notes. These points cannot be manually selected, and are instead picked at random within the shape. This in turn allows for an accurate sonic representation of the shape through randomly distributed points, where denser areas of a shape have a greater amount and intensity of triggered notes. The small amount of user input includes basic functions like tempo and number of points, but uses an intentionally simple interface that contains only general vocabulary as opposed to music-specific or plant-specific terms.

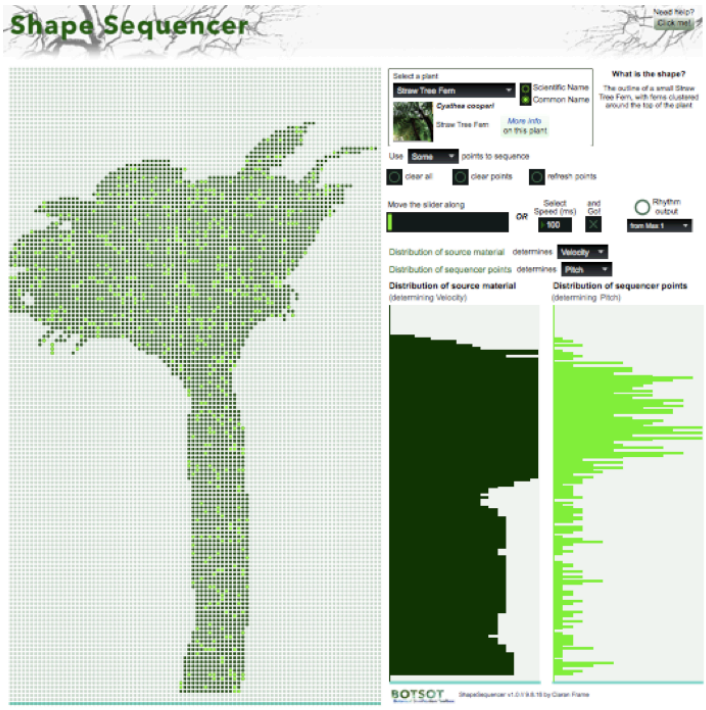

Figure 7 – Shape Sequencer interface (randomly selected points in light green)

5.2 Keyword Synth

The Keyword Synthesiser is a simple additive synth that generates a unique, playable sound for any plant species through a series of saved lookups based on keyword matching. By using the most common 200 words from scientific descriptions of plants and grading them against predetermined sound criteria, variables of the Tal Noisemaker synth [15] are altered based on an input scientific description of any given plant. Descriptions have been chosen as a data source in this module because of their ability to objectively and scientifically capture physical aspects of any given plant. Chromatic and spatial homogeneity were both identified as symptomatic features of plant blindness by Wandersee et. al [1]. Scientific descriptions of plant species can act as a partial solution to these problems by objectively revealing physical composition and standardised characteristics of plants. In order to generate unique sound synthesis from these keywords, a small database of keywords was constructed that references manually entered fitness scores that correlate to a particular synthesiser variable, as outlined in Table 3.

Table 3 – Controlled variables used for fitness scores in Keyword Synth

Synthesiser Variable	**Integer scale**	**Description**
Waveform Type	1–10	Sine–Noise
ADSR Shape	1–10	Exponential–Linear
ADSR Variation	1–10	Low rate of variation–High rate of variation
ADSR Transitions	1–10	Short–Long
EQ Frequency	1–10 where 5 is a flat response	Low Frequency–High Frequency

EQ Type	1–10	Notch–Pass
EQ Events	1–10	Number of discrete EQ events
LFO Frequency	1–10	Slow–Fast
LFO Amplitude	1–10	Low–High
Intensity	1–10	Small–Large (majority distortion)
Range	1–10	Limited–Wide pitch range (where 1 is mono)
Temporal Evolution	1–6	1 + 2 + > - > + 3 + > - 4 - > + 5 - > + > - 6 -

Descriptions can be entered into the Python script, which extracts the weighted average score for each of these categories based upon the previously entered data, and applies these scores to the aforementioned variables on the synth. Thus, each species is assigned a unique tone colour, representative of the objective physical characteristics of the plant. The resultant synth patch may then be triggered from other modules.

5.3 DNA Sequencer

The DNA sequencer is a simple rhythm machine based upon the unique genomes of every plant. All sequences of DNA from any living organisms can be broken down into four bases – Adenine, Guanine, Thymine and Cytosine. The DNA Sequencer takes these remarkably simple yet powerful building blocks, and translates them into rhythms. Not only are these sequences unique, they also inherently consist of patterns and repetitions – a feature that is suited to the creation of rhythm, as discussed in [16].

The sequences themselves originate from plants surrounding the University of Sydney main campus. When this data is collected, there is always a large amount of ‘non-coding’ DNA present within the sequence (as is the case for all living organisms) – that is, DNA that does not directly translate to proteins and thus characteristics and unique aspects of a particular species. For this reason, the DNA sequencer aims to use extracts from sequences that share a fundamental relationship with the plant (for instance, a section of the DNA sequence responsible for the purple colour of flowers on the *Jacaranda mimosifolia*). In this way, a systematic representation of the sequences within a given plant species can be formed through a relatively small sample of data.

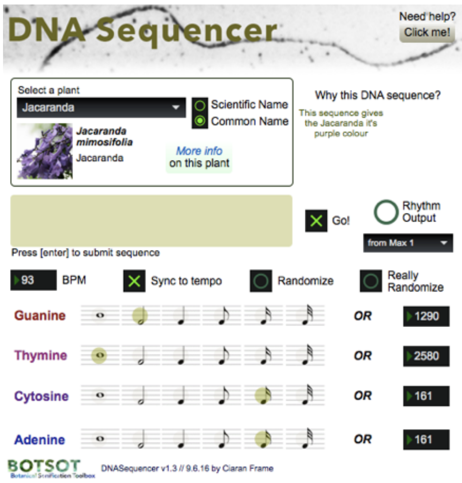

Figure 8 – DNA Sequencer interface

5.4 Image Envelope Generator

Any given species of plant exhibits any number of remarkable patterns and shapes, whether it be the curve of a leaf or a ripple in bark. These unique profiles and structures serve a purpose to the plant, and are present as a result of evolution. The input data for this module is a simple photo of a visible aspect of a plant species. From this image, an envelope is generated that is then transformed into musical information in the form of evolving MIDI data, using a slider to 'play' the envelope. This MIDI CC (continuous control) information is useful for mapping to temporal variables, and has been mapped to pitch and effects levels in arrangements thus far.

The module uses the Sci-kit Image library within Python, specifically the Canny edge detector. This edge detection algorithm uses a multi-stage process based on Gaussian filters to find the most prominent edges of any given image. In line with 'curatic data', users may also input their own macro and micro images for use in the module, as well as being able to choose from presets.

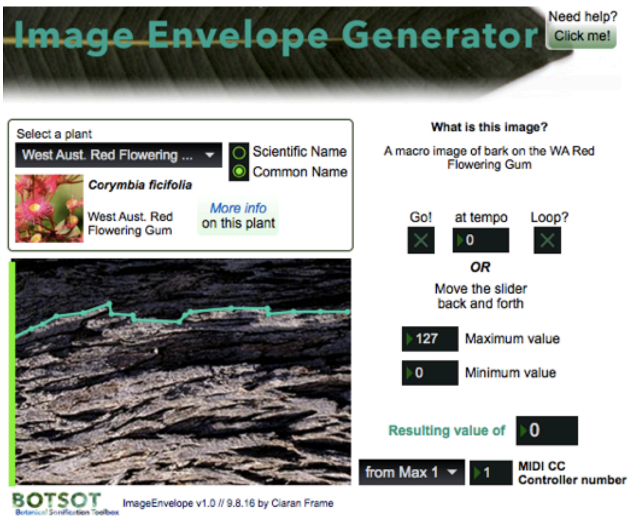

Figure 9 – Image Envelope Generator interface

5.5 Additional modules and supplementary material

In line with precedent of providing an environmental context to generative music, field and contact microphone recording modules have been created for BOTSOT in order to provide a sonic anchor for the listener. Recordings of sounds heard every day from plants (for instance, the rustling of leaves) are important to the toolbox, as they act as a foundation for the context in which other abstracted sounds may exist.

Figure 10 – Collection of contact microphone recordings

Field and contact microphone recordings were extracted over a period of five months in order to capture audible environmental sound of numerous plant species. Within BOTSOT, users may trigger these sounds through MIDI or through simple playback, accessible from a large archive of indexed recordings. Field recordings provide macro context on a human scale, and contact microphone recordings uncover minute sounds and vibrations of resonant bodies through the use of an extremely sensitive diaphragm. Their use in the context of BOTSOT leads to a greater understanding on the user's part of the inner resonances and unique characteristics of the natural excitatory vibrations almost 'performed' by the species.

6. The Future

In early 2018, BOTOST will undergo its first live iteration. As an extension of heightened understanding of a given plant species, the audience will connect to various plant species through Bluetooth Low Energy controlled through a Raspberry Pi. The BLE connection will provide a simple web interface with a limited version of some BOTSOT modules, with audiences able to take part in their own unique interactive sonic tour, encouraging comparison in a physical context. In further development, BOTSOT will adapt to be used in a standalone software context.

7. Conclusion

BOTSOT has explored a unique approach to generative music, using fresh elements of model-based sonification as guides to forming a generative toolbox that encourages a greater understanding of plants through sonification of data and musical variations. Through the use of curatic data and a unique take on the human-computer interface, the resultant toolbox has formed new creative processes, uncovering an extra dimension of observation that cannot be achieved by simply observing a plant more closely. Throughout the process, BOTSOT has illuminated detail and valuable information from plant species, both seen and unseen, to provide a framework for music creation that fosters understanding of botany as well as individual creativity in generative music.

For further examples, please see http://www.ciaranframe.com/botsot

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