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Composing [De]Composition: Data Sonification for Sound Art and Music Composition

A Dissertation submitted in partial satisfaction
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by

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DEDICATION

To my loving husband, Anas Etan.

You have helped me to fill my life and our compost bin.

ABSTRACT OF THE DISSERTATION

Composing [De]Composition: Data Sonification for Sound Art and Music Composition

by

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Composing [De]Composition was a large-scale BioArt research installation presented at the University of California Riverside's *Sweeney Art Gallery* from June-October 2015. This paper introduces compost—the main material of *Composing [De]Composition*—as a rich site for creative exploration and expression via the medium of data sonification. Here, the author non-reductively describes the multi-agential and poly-temporal nature of compost and data sonification through detailing the evolution of a process-based, techno-ecological artistic praxis involving: the observation, audification, and sonification of compost temperatures; the development of new sensing methods for data collection; parameter mapping; audio display/spatial sound design; dataset-based digital music composition and musification for acoustic instrumentation.

The main observable driving the project is incalescence—the heat generated by the composting process. During the exhibition/research period, audification of this biological process brought a perceivably silent activity into the tangible reach of human hearing. The collection and real-time audification of temperature data using a custom interface to route sensor data to an eight-point audio display enabled listeners to better

apprehend the complex ecology of a heterogeneous mass that was simultaneously decomposing, supporting a myriad of life forms while also enabling the bioavailability of macronutrients to the soil.

The recontexualization of compost temperature data into sound also creates fertile ground for exploration in the realm of music composition. While the collection of data over time depicts inherent patterns occurring in the system analyzed, the basis of music also builds upon the use of patterns—pitched, rhythmic, and dynamic—through time. Sonification of compost temperature patterns not only capacitates human auditory observation of what is normally a perceivably silent physical biological process but also enables the composer/sound artist to create compositions in partnership with her phenomenon of study.

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CHAPTER 1: INTRODUCTION AND A SHORT SURVEY OF DATA SONIFICATION TERMINOLOGY, CURRENT TECHNIQUES AND SONIFICATION ART PROJECTS

INTRODUCTION

Organized as a large-scale data sonification research installation presented at University of California Riverside's *Culver Center for the Arts* from June 27th–October 17th 2015, *Composing [De]Composition* introduces the material of compost as a rich site for creative exploration and expression via the media of data sonification, music, and installation art. The primary material for *Composing [De] Composition* is decaying organic matter—compost—a silent, complex, living matrix. The project is a practice-based approach toward compost and the sonification of data collected from it as a site of creative expression.

I cite Don Idhe's material hermeneutics as a point of departure—

> For science, or art, to be experienced, it must take into account human embodiment… if the phenomenon lies beyond our capacity, then only by being technologically transformed can it come into our range. [1]

Data sonification effectively provides an answer to Idhe's question—How can we hear that which is silent? [2]—first posed in his 2009 *Postphenomenology & Technoscience*. The practice of sonification and sonification art transform data from normally silent processes and systems into the aurally conceivable.

Working directly with compost generated from my own daily life afforded me the chance to develop an evolutionary and techno-ecological artistic praxis centered upon observations made over a research period of approximately two years. The time-based installation work and resulting music compositions reveal the inherent multi-agential and poly-temporal nature of compost—a normally silent process—as an artistic material and muse. *Composing [De]Composition* is also a response to the growing body of art/music based on environmental data, especially with regard to the issue of global warming. While many works dealing with data sonification engage with big data and large scale environmental issues, the approach used for *Composing [De]Composition* is to collect data from a more "ordinary" and accessible source.

The main observable driving the project is incalescence—the heat generated by the composting process. This perceivably silent biophysical activity is brought into the tangible reach of human hearing through temperature data sonification—which translates the temperature data into sound. Data sonification can be defined as

> the data-dependent generation of sound in a way that reflects objective properties of the input data. Sonification… research takes place [through an interdisciplinary process that includes] physics, acoustics, psychoacoustics, signal processing, statistics, computer science, and musicology. [3]

The collection and real-time sonification of temperature data using a custom interface to route sensor data to MAX/MSP enables listeners to better grasp the complex ecology of a heterogeneous mass that is simultaneously decomposing, supporting a myriad of life forms while also enabling the bioavailability of macronutrients to the soil. In addition, the recontexualization of data into sound creates fertile ground for compositional exploration, as the collection of data over time depicts inherent patterns occurring in the system analyzed, while the basis of music also builds upon the evolution of pitch and rhythmically based patterns through the temporal matrix. Sonification of these temperature-based patterns enables the composer/sound artist to create works in partnership with her subject/phenomenon of study.

In the year leading up to the exhibition period, strategies for the real-time sonification of compost temperatures—known as *audification*—focused primarily on the development of sensing methods and sound-mapping strategies. The opportunity to develop a public, gallery-based research laboratory at the university's main art venue from June-October 2015 further challenged me to engage visitors not only with the novel act of listening to compost temperature data, but also to encourage them toward developing environmentally sustainable practices in their own daily lives through home composting.

During this time, the *Sweeney Art Gallery* was used as an active BioArt research lab. Visitors to the installation experienced the biota elaborated as the gallery's soundscape via real-time audification of temperature data and stop-frame animations of the vegetal material inside the gallery's compost container. Visible scanning electron microscope images of the biota magnified at 100-5000 times also revealed microbial life responsible for generating the heat, and an ongoing research wall exhibited examples of my sensor research, parameter mapping/data translation into sound and music, and general information on composting. Moreover, the instrumentation/performative possibilities inherent in using the sensor apparatus was also investigated during the task of adding new organic matter to the compost bin.

The live, temperature-based soundscape was projected thorough a biodegradable[*], eight-point audio display mapped to mirror the placement of the temperature sensors

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[*] In an effort toward achieving sustainable sound-art and design practices, the custom speaker housings I designed for the installation's audio display were fully biodegradable—created out of organic matter, wire, and University of California campus newspapers/local supermarket advertisements.

inside of the on-site compost container. At the October 2015 closing of the study, a "data listening session" was presented to an audience of UCR faculty, students and members of the general public. During the event, the minute-by-minute temperature changes recorded within the biota over a 30-day period was translated into a 30-minute spatialized, microtonal sound composition. A real-time, 200x magnification of the biota was also projected onto a gallery wall—giving audience members a view of thousands of microorganisms at work.

The following strategies were deployed in the development of the long-term sonification art project:

1. Research on the aerobic composting process and investigation of how to collect the most meaningful data from the mass;
2. Development of the temperature sensing apparatus and MAX/MSP coding to collect, store, and audify the data;
3. Design and creation of the *in situ* compost sonification research lab at UC Riverside's *Sweeney Art Gallery*;
4. Analysis, translation, and sonification of data gathered during the exhibition;
5. Re-translation of the dataset for musical and other artistic exploration.

The remainder of this chapter gives a short survey of terminology and techniques of data sonification, concluding with a discussion of three data sonifcation projects by other artists. Chapter two introduces and describes the complex, process-based techno-ecology that developed over the course of my research period for creating this sonification art project. Chapter three offers a deep description of *Composing [De]Composition* detailing my observations on: 1) Compost as a site of creative expression; 2) Developing praxis and tools and MAX/MSP objects for sonifying compost temperature; 3) An overview of parameter mapping strategies for the initial outdoor compost temperature study and the subsequent indoor gallery-based study; and 4) The presentation of a public “Data Listening Session” at the exhibition closing.

Chapter four contextualizes the project within the framework of process-based music and discusses the latent opportunities for artistic agency when sonifying data sets. Using process and agency and the work of American composers John Cage and Morton Feldman as a springboard, my discussion then turns to an analysis of two score-based musical works developed from data sets collected over the two-year research period:

1. *Desert Winter* (2014): A work for solo piano, based on the MIDI note number mapping of a preliminary 45-day outdoor compost temperature study;
2. *Sweeney Summer 2* (2016): A work for violin, percussion and piano, based on the results of the 30-day *Sweeney Art Gallery* study mapped to chromatic and quartertone scales.

Chapter four closes with my conclusions regarding *Composing [De]Composition* in the context of the various forms of data sonification.

A Short Survey of Data Sonification Terminology, Current Techniques and Sonification Art Projects

Composing [De]Composition was a a deep exploration into the creative use of datasets as a source of sono-musical expression.large-scale investigation into the areas of data generation, sonification and collection. In this next section, I will first define some key terms associated with data sonification, and then discuss current techniques and approaches. The chapter concludes with a survey of projects by other artist/practitioners currently working in this field.

KEY TERMINOLOGY and APPROACHES

Audio Display

The field of audio display research first catalyzed with the establishment of the first *International Conference on Audio Display* at the Santa Fe Institute, in Santa Fe, New Mexico in 1992. According to Walker and Nees,

> An auditory display can be broadly defined as any display that uses sound to communicate information. Sonification is a subtype of auditory displays that uses non-speech audio to communicate information… seek[ing] to translate relationships in data or information into sounds(s) that exploit the auditory perceptual abilities of human beings such that the data relationships are comprehensible. [4]

An example of an auditory display that might be familiar to most readers is the beeping sound associated with an electrocardiogram machine measuring a hospital patient's heart rate. First, the patient is outfitted with the machine's electrodes that measure the body's electrical current as the heart is pumping. A continuous, regularly repeating, impulse-based sound matching the rise and fall of electrical current as the heart beats is emitted out of the machine's speaker, indicating that the patient has a constant heart rate. Any changes in the patient's heart rate are reflected in an irregular rhythmic pattern, and cardiac arrest—a stopped heart rate—would be indicated by a flat-line constant tone.

Hermann, Hunt and Neuhoff expand upon and further refine Walker and Nees' broad definition of auditory display above, explaining that the term

> encompasses all aspects of a human-machine interaction system, including the setup, speakers or headphones. Modes of interaction with the display system, and any technical solution for the gathering, processing, and computing necessary to obtain sound in response to the data. In contrast, *sonification* is a core component of an auditory display: [defined as] the technique of rendering sound in response to data and interactions. [5]

The function of auditory displays have been described and broadly categorized as falling into one of four categories: alarms/alerts/warnings; status/process/monitoring messages; data exploration; and those for art/entertainment/sports/exercise. [6] Audio displays falling into the *alerts* category refer to sounds indicating something has occurred, but do not indicate any other type of information. *Monitoring* messages are more dynamic than those in the *alert* category and depend on the listener's ability to detect small changes in events. *Data exploration* auditory displays

> use sound to offer a more holistic portrait of the data set or relevant aspects [of it, are] …intended to encode and convey information about an entire data set or relevant aspects [of it] rather than condensing information to capture a momentary state such as with alerts and process indicators. [7]

Data exploration auditory displays either may allow users interactively navigate the dataset, or be presented in "concert mode"—also known as *process monitoring*—indicating a strict reading of the data set with no possible interaction by the listener.

For the purposes of this discussion, three examples of data sonification for arts/entertainment will be described in a section below titled *Sonification as Art*. An instance of the use of auditory displays for exercise is the alarm/beeping sound emitted from a heart monitoring exercise bike when the user's self-programmed desired heart rate is reached. In addition, Yang and Hunt have prototyped a system that "uses real-time sonic feedback to help improve the effectiveness of a user's general physical training. It involves the development of a device to provide sonified feedback of a user's kinesiological and muscular state while undertaking a series of exercises". [8] The development of audio displays for exercise will most likely increase exponentially in years to come, and consumers will undoubtedly see more sophisticated technologies designed to track physical performance enter into the market.

Data Sonification Approaches

According to the *International Community of Audio Display* website, sonification is defined as data-controlled sound. [9] Hermann, however sets out a very strict definition of what exactly qualifies as a sonification, emphasizing the scientific utility of it. Hermann points out that

> Sonification refers to the algorithm that is at work between the data, the user, and the resulting sound. Often and with equal right the resulting sounds are called sonifications. A technique that uses data as input, and generates sound signals... may be called sonification *if and only if* (my emphasis): 1) the sound reflects *objective* properties or relations in the input data*;* 2) The transformation is *systematic*; 3) The sonification is *reproducible*; 4) The system can intentionally be used with *different data*, and also be used in repetition with the same data. [10]

There are many different approaches toward the realization of a data sonification. In 1994, Carla Scaletti "classified sonification mappings by level of directness: (0) [for] audification; (1) [for] parameter mapping; and (2) [for] a mapping from one parameter to one or more other parameters. [11] Hermann has created the excellent visualization based on Scaletti's observations (Figure 1.1) to explain data sonification and the various techniques associated with it. The light brown boxes that extend outward from the main container labeled "Sonification" name the various techniques used and approaches toward the sonification of data. Here, Hermann echoes Scaletti's idea by organizing the various sonification techniques in the order of relative time neede to develop the sonification—beginning with audification in the upper left, through parameter mapping, model-based sonification, and extending to techniques "yet to be discovered".

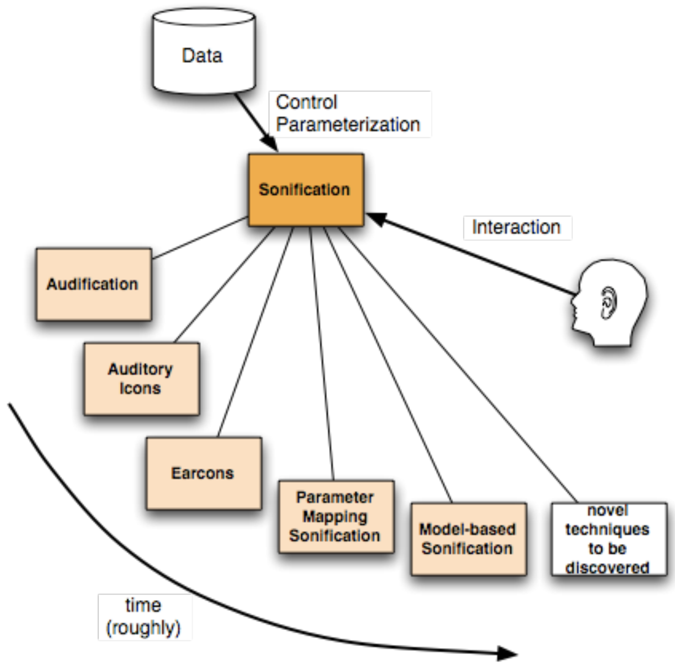

Figure 1.1: Diagram of sonification techniques. ©Thomas Hermann 2010.
http://sonification.de/son/techniques. Used with the author's permission.

Time Series and Audification

In 2004, Kramer and Walker defined *audification* as:

> the direct translation of a data waveform into sound. This often requires that the data wave be frequency-shifted into the audible range for humans, or time-shifted (slowed down or sped up) to allow for appropriate inspection by the listener. [12]

Datasets that consist of single points of information collected over a continuous time intervals using successive, equal measurements are defined as a *time series*. Time series based datasets are best for audification. Since each data point of an audification is represented as a single audio sample, "conceptually, canonically ordered data values are used directly to define the samples of a digital audio signal". [13]

Grond and Herrman explain the process of data audification as thus:

> The data are usually loaded into a sound buffer and directly sent to the digital/analog converter… The direct conversion of data into sound is a good choice if the data of interest exhibit the following properties: first, they have one dimension and can be interpreted as time. Second, the sampling rate along the temporal dimension is sufficiently high to adequately represent the underlying dynamical process. If both requirements are met, then the variations in the data such as dynamical properties like oscillations and transients are often recognizably "translated" into the perceived sound… In fact, the data recording sensors can in these cases be thought of as microphones, which are sensitive above and mostly below the audible range. In this case, sonification has an indexical function similar to that of sounds from field recordings. [14]

Scaling of data in terms of frequency shifting is of course necessary if the absolute values of the data in question don't already fall within the audible range of human hearing—20-20,000 Hertz. For example, no scaling need be done on the dataset if the range of values coincides with the human auditory threshold, and a direct one-to-one translation into frequency can be performed. However, if the data values fall below or above this range, some sort of scaling must be performed in order for the data to be heard.

I do not entirely agree with Walker and Kramer's above definition of audification with respect to factors of time shifting, however. A time-shift in the reading of a dataset contradicts Grond and Hermann's categorization of an audification being a direct, digital/analog conversion—placing the focus of the sonic results more into the realm of data *interpretation*, as different time scales would render different results. In light of this, for the purposes of this project I will define audification as the real-time translation of data to sound.

One of the earliest invented audio displays enabling audifications of our environment is the Geiger counter, a device first invented in 1928. The Gieger counter is used to detect the presence of radiation particles in an environment, signalling their presence with an audible click. As the radiation level increases in the area tested, so does the number of successive clicks heard. Geiger counters provide a direct reading of the environment the user is navigating—functioning like an amplified microphone to create a real-time, site-specific experience.

Auditory Icons, Earcons, Parameter Mapping, and Model-Based Sonifications

Auditory Icons act similarly to visual icons, and are brief sounds used to metaphorically represent a process. A familiar auditory icon to readers working on a Macintosh computer would be the computerized sound of paper crumpling when digitally emptying the 'trash' folder, or the pre-programmed chord that plays through the computer speakers upon startup of the operating system. Although there is no actual paper involved in erasing files off a hard disk, the simulated sound acts as a metaphor representing the physical act performed in the three-dimensional realm.

An *earcon* is a type of data exploration auditory display that is used to signify a change of status within a system. The actual sonic material of an earcon does not need to relate directly to any aspect of the information it represents. Instead, the relationship must be learned. Unique ringtones assigned to specific people in a cell phone contact list is a familiar example of an earcon. The choice of sound/tone is arbitrary, yet over time we associate the sound with the person who is calling. [15]

Parameter mapping sonification is the most commonly used method of data sonification and occurs when attributes of sound such as pitch or amplitude are mapped directly to the dataset. Cook defines *parameter* as "a (likely continuous) variable that, when changed slightly, yields slight changes in the synthesized sound, and when changed greatly makes great changes". [16] The resulting sonification is the playback of all data points in the dataset.

"Parameter mapping [is event based and] represents changes in some data dimension with changes in acoustic dimension to produce a sonification". [17] According to artist Andrea Polli, sonification—although like audification—involves "choosing the phenomena to sonify, kind and format of numerical data to be output, possible parameters of sound itself, rate of play, pitch timbre, rhythm and duration [sonification]… allows control of speed and scale far beyond the control afforded by audification". [18] A storm-based parameter mapping sonification created by Polli and a team of climate scientists will be discussed in more detail in the section below.

Another methodology used to bring data into the audible realm is *model-based sonification.* While parameter mapping sonifications are event-based, Walker points out that model-based sonifications turn data into dynamic models rather than sound,

> Sound… has a multitude of changeable dimensions that allow for a large design space when mapping data to audio… Model-based approaches of sonification differ from event-based approaches in that instead of mapping data parameters to sound parameters, the display designer builds a virtual model whose sonic responses to user input are derived from data. [It] is a virtual object or instrument with which the user can interact, and the user's input drives the sonification… and relies upon the active manipulation of the sonification by the user .[19]

Thomas Hermann is one of the leading researchers of model based sonification (MBS). According to Hermann,

> Model-based sonification mediates between data and sound by means of a dynamic model. The data neither determine the sound signal (as in audification) nor features of the sound (as in parameter mapping sonification), but instead they determine *the architecture of a 'dynamic' model,* which in turn generates sound.[20]

Hermann delineates that the data space and the model space in a MBS are distinct. An example of a model used in this type of sonification is the principal curve sonification (PCS) in which data is interpreted along a three-dimensional acoustic spiral. [†] This type of sonification is of a higher order than those previously described, and interpretation by the user must first be learned. In MBS, "the data is not 'playing' the instrument, but the data set itself 'becomes' the instrument and the playing is left to the user". [21] As such, the model-based approach creates virtual sounding objects.

In summation, the term data sonification covers a vast array of techniques and end uses. Data sonifications can be utilized to represent data collected in real-time, signify designer-defined changes within a dataset-based process, and/or illustrate the trajectory of a dataset. Most interestingly, they can even be used to dictate the outcome of a user's interaction with a hands-on interface. The next section will discuss how sonification has been employed to creatively communicate datasets in the public sphere.

Sonification as Art

Auditory displays are gradually gaining increased recognition as a technique for presenting data as sonic information in a variety of contexts. According to Sinclair,

> There is a new, or perhaps renewed, consciousness of the particularities of aural perception, and we are learning to consider clicks, beeps, varying pitches or chords as carriers of significant information. Although much of this evolution is taking place in the technical realm, as a way of enhancing a user's perception of important data, notably when their other senses are occupied, interest in data sonification is also increasingly apparent in the realms of art and music. Artists are using sonification to introduce ''real-world'' or ''real-time'' elements into

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[†] For a complete discussion of this, sound examples and other MBS, see Hermann, "Model Based Sonification" http://sonification.de/handbook/index.php/chapters/chapter16/#S16.4

> their work, and composers are abandoning human decision-making and fixed scores to leave space for variation derived from incoming data. [22]

The following section examines three sonification projects that fall into the contexts of music, art, and various strains of activism. Although the general public's awareness of data sonification is not quite on the same level of its familiarity with data visualization, I contend that the apprehension of datasets on the aural realm allows listeners to experience inherent patterns on a physical, visceral, and possibly even emotional level. Take for example, the attitude of artist Andrea Polli, who works on sonifying weather systems:

> In my artwork, I have tried to develop strategies for the interpretation of data through sound that has both narrative and emotional content… an emotional connection with data can increase the human understanding and appreciation of the forces at work behind the data. [23]

Thus, artists such as Polli use sonification to enable listeners to assimilate data in a physical way.

One sonification artwork that clearly illustrates how data sonification can elicit strong emotional reactions is Guillaume Potard's sonificiation titled, *Iraq Body Count*.❖ According to Potard—"a sound scientist who has a PhD in 3D audio" [24] —the foreground of the work is a sonification of two sets of collected data on (1) Iraqi civilians and (2) US and British soldiers who were killed in the first Iraq war between the months of January 2003 to April 2004. Foreign soldiers and Iraqi civilians are each assigned separate, impulse-based sounds with each death/type indicated by repetition of that specific sound. Potard also assigns different signal amplitudes to each "body type" associated sound. The

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❖ Available on https://soundcloud.com/somatic-sounds/iraq-body-count-guillaume-potard. The sound file also includes Potard's explanation of his data-to-sound mapping.

sound representative of a soldier's death is assigned a higher amplitude than the sound indicating a civilian's death. It is clear that Potard intentionally curated his sounds in accord with Western current political attitudes regarding how civilian death is viewed as "collatoral damage"—i.e., lower in volume—while the deaths of members of the invading forces are louder, and therefore in some way more "valuable".

The resulting pointillistic, irregularly-patterned body count sonification was then juxtaposed over a drone-based sonification based on fluctuations in the daily price of *NIMEX* crude oil during that same time period. The variation in the NIMEX mapping is realized as upward and downward variations in the drone's pitch. The timeline of the datasets/sonification begins two months before the armed conflict occurs in the region—acting to illuminate the severity of the situation once the carpet-bombing attacks commenced in the area**.** Potard's three-minute sonification is a powerful and haunting tribute to the 10,800 Iraqi civilians and 846 soldiers who died in the first year of the conflict, and is a clear indicator of how hearing data over visualization of it can significantly increase its impact on an audience.

Other artworks based in data sonification engage with big data and issues of global pollution, storm and weather patterns, tsunami waves, earthquakes, outer space, train schedules, and human DNA, to name a few. Projects of note in this category include Chris Chafe's use of Blackcloud Citizen's Science League's worldwide sensor readings for carbon dioxide levels, humidity, and concentrations of volatile organic compounds from locations including Katmandu, Shanghai and Tokyo to influence different aspects of the musical components of his data 'musification' work, *Smog Music* (2008)[‡], Dombos and Brodwolf's sonification of the 2011 Tohoku earthquake off of Sendai Japan[§], and Andrea Polli's *Atmospherics/Weatherworks: the Sonifcation of Meterological Data* (2002) dealing with data on major storms in the New York metropolitan area. While the work of Polli and Dombos and Brodwolf's are clearly rooted in the realm of data sonification as discussed above, Chafe instead prefers to classify his work as 'musification'. Chapter four below includes a deep discussion of my research into the differences between sonifying and musifying the same dataset.

The aesthetic potential of sonification as an artistic medium has been developed by sound artists like Andrea Polli who made extensive use of sonification techniques in a public sound art installation on climate change. An artist, researcher and educator, Polli has exhibited, performed, and lectured nationally and internationally—sharing her artworks "that translate numerical data into sound, [ranging] from algorithmic compositions modeling chaos to live improvisation using video tracking systems". [25] One area of particular interest to Polli is the role data sonification can play to illustrate complex information as soundscapes. Polli believes that sonification, and audification in particular is closely related to soundscape or field recording:

> Audification, the process of taking a vibration signal [that can be] outside the range of normal human hearing and shifting it into the audible range, is closely related to soundscape or field recording in that it involves technological mediation of signals in the environment… listening to an audification of an environment can provide an opportunity to re-establish an ecological link with the source of information… when custom systems detect and record [and even create] sounds

‡ http://chrischafe.net/smog-music/

§ https://www.youtube.com/watch?v=3PJxUPvz9Oo outside the normal range of hearing, listeners are allowed to hear sound universes previously undetectable. [26]

A project that takes Polli's use of audification as soundscape and further expands it into parameter mapping sonification is *Atmospherics/Weather Works* (2003). Polli and climate scientist, Glenn Van Knowe, working in collaboration with atmospheric scientists to develop systems for understanding storms and climate through sound, [27] sonified extremely large and detailed atmospheric data sets collected by Mesoscale Environmental Simulations and Operations (MESO). The interdisciplinary group produced a series of multi-channel sonifications based on two historical storms that passed through the same region in New York/Long Island—1979's "President's Day Snowstorm" and 1991's Hurricane Bob. One sonification was realized as a 15-channel sound installation that recreated the two storms spatially at five different elevations. The spatialized installation allowed "listeners to experience geographically scaled events at the human scale and gain a deeper understanding of some of the more unpredictable complex rhythms and melodies of nature". [28]

Polli and her team selected parameter mapping sonification as their approach for the project—directly mapping six weather variables to pitch—"using long tones for temperature and pressure variables and percussive tones for water related variables". [29] The group used wind speed to determine the amplitude of each sound; and sound samples of breath rushing through a wooden flute to represent atmospheric pressure. Polli "used the stream of numbers as variables for shifting and filtering sounds with a wide frequency spectrum [i.e., noise]". [30]

The numbers represented “shapes or curves in the character of [the] sound itself rather than notes in a musical composition”. [31] For example, noisy sound samples such as insect sounds, and sounds of rushing water were pitched via a band-pass filter determined by dew point values, and another sound had a band-pass filter determined by relative humidity. An overall narrative to each storm sonification composition was developed through the use of global scaling associated with each of five elevations of the storm. A data set was formed for each elevation creating increasing and decreasing intensity through varying amplitude via wind speed.

Polli believes that sonifying entire storm systems humanizes them and allows audiences to relate to them on an embodied, physical level:

> The scale of the data set ultimately sonified can be far outside of possible human experience, for example, vast geographical distances shrunk to the size of a room and long time periods compressed into a few minutes… Creating sonifications using… soundscape composition as a model may serve to humanize the resulting sonification work by bringing the data to human scale and by allowing audiences to relate to the sonification on a physical level. This might serve to increase environmental knowing by allowing listeners to experience data *through* (author’s emphasis) their bodies. [32]

According to Polli,

> Although the radical nature of the process of audification and data sonification may seem to take one out of his or her environment, this process of reshaping and reordering information may actually bring one closer to the natural world… re-establishing a link between data, communication, and the environment.[33]

Although the main goals of *Atmospherics/Weather Works* was to develop sonifications for installations and music performances, it was also necessary to first develop a software system using MAX/MSP to read and sonify the data. The team also produced a website[**] where visitors could interact directly with the data sonifications. Thus, the sonification project continues beyond the lifespan of the physical artwork.

In contrast to the approaches toward using predetermined datasets for sonification addressed in the abovementioned works, New Orleans-based artist Quintronics and the Robert Rauschenberg Foundation have developed the *Weather Warlock* (2014). *Weather Warlock* is a low-voltage weather controlled, drone-based synthesizer driven by real-time, site-specific temperature, wind, sun, and rain data. The *Weather Warlock* senses moisture, light, wind, and temperature to control an eight oscillator analog synthesizer—"produc(es)[ing] a wide range of tones and harmonics based around a consonant E major chord with special audio events occurring during sunrise and sunset". [34]

Weather Warlock creates and directly streams the online data audification in real-time from Quintronics' New Orleans base station. At any time, listeners located worldwide can tune in and listen to the live, climate controlled synthesizer-based audification via the internet. Quintronics states on the website that one of the main reasons behind the project is to provide listeners a direct musical connection to nature in the hopes of helping them dealing with stress, sleep disorders and/or health issues. [35]

Quintronics explained how data on each of the abovementioned four weather conditions—called "rain", "sun", "wind" and "temp" respectively—control the synthesizer's output. Rain controls three oscillators, sun is assigned one oscillator, and both "wind" and "temp" (which make up the E major chord) use two oscillators each. According to Quintronics,

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[**] www.andreapolli.com/studio/atmospherics/

> Rain is simply using a drop of moisture from the atmosphere to complete a circuit. Wind is using standard anemometers to open a low pass filter once per rotation on the high octave and 5th. Sun is an oscillator which is always on but is too high for human hearing during sunlight hours and basically off at night... it is calibrated to enter our hearing range during periods of low light, such as during sunrise, sunset, or a cloudy storm. [36]

In addition, the project's main website has archived five past audifications titled "Sunrise", "Storm", "Work", "Sleep", and "Relax", with the "Sunrise" recording made sometime in the Spring of 2015. According to Quintronics, temperature is controlling the rate of a gradually accelerating impulse sound that is heard in the 40-minute recording. The acceleration of the impulse indicates that the atmospheric temperature is rising. Quintron has also traveled outside of the New Orleans area with and *Weather Warlock* to perform weather-based music. Quintronics admitted that in live situations, "I often bypass that feature to manually control the phasing speed... fun!" [37]

After laying the basic groundwork necessary to ease the reader into the world of data sonification, its art, and its ability to aurally reveal the dataworlds of war and climate change, in the next chapter I will turn toward describing the intricate techno-ecology involved in the development of my own compost temperature data sonification project, *Composing [De] Compositon.*

<u>Notes</u>

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16) Perry R. Cook "Sound Synthesis for Audio Display," in *The Sonification Handbook,* eds. Thomas Hermann, Andy Hunt, John G. Neuhoff (Berlin: Logos Verlag, 2011), 198.
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30) Polli. "Soundscape", 263.
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35) Ibid.
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CHAPTER 2: A TECHNO-ECOLOGICAL APPROACH: CONTEXTUALIZING DATA, COMPOST, ART, AND SUSTAINABILITY ††

Chapter two of this discussion introduces the 'techno-ecology' of *Composing [De]Composition*. To begin, I will first I will trace the evolution of the concept of 'techno-ecology' through the writings of anthropologists, **political theorists,** and new/post media artists/thinkers. Secondly, I will briefly describe the project and my choice of compost as an artistic medium. Next, I will use Smite and Medosch's premise of "contextual seedbeds" as a framework to describe my own techno-ecological praxis in the development of *Composing [De]Composition*. Finally, the chapter concludes with a discussion of the project in relation to its human and non-human agents, and environmental sustainability.

From Ecology to Techno-Ecology

I will first I lay the groundwork for *Composing [De]Composition* as a 'techno-ecology' by tracing the concept's evolution through the work of political theorist Jane Bennett, anthropologist Bruno Latour, and new/post media artists/thinkers Roberta Buiani, Rasa Smite, Armin Medosch, Ratis Smits, Eric Kluitenberg and Beatriz DeCosta. Political theorist Jane Bennett developed the idea of "vital materialism" to describe the intricate relationship that has developed between humans and "things." Bennett investigates "the proliferation of entanglements between human and nonhuman materialities", [1] arguing that non-humans—

†† Chapter two of this dissertation is based on a forthcoming article in *Acoustic Space Journal* (16), published by RIXC, The Center for New Media Culture and the MPLab, Art Research Lab of Liepaja University.

> trash, bacteria, stem cells, food, metal, technologies, weather—are actants more than objects... "Objects" appear as such because their becoming proceeds at a speed or level below the threshold of human discernment.[2]

While Bennett's writings deal with humans and their relationship with the non-human, Roberta Buiani examines ecologies that develop between people and their technologies. In her article "Ecology and Sustainability in Art and Science" (2014), Buani explains that the original notion of *ecology* stems from the Greek word for 'house' or 'dwelling', "and is widely used to designate the study of the interactions among organisms and their environment". [3] Integrating Bruno Latour's (1991) concept of uniting the "Great Divide" between nature and culture via hybridized technological networks, Buiani extends the original Greek interpretation to include contexts outside of the 'naturally' occurring environments that humans inhabit to also include environments we *create* while working in the areas of science and media:

> When used in the context of science and media, ecology designates a series of relations coagulating around a specific topic, discipline or phenomenon… [this] includes the intersections between humans and other objects, instruments and processes, the organic and the non-organic, the relations between and the activity of scientists and artists, scientists and the public, etc… Ecology here designates an assemblage of media, a conglomerate of practices, a mix of ineffable ordinary (and not-so-ordinary) affects that intervene in realizing the intersection of human and non-human actors. [4]

While Bijker et. al. (1987) conceived of a somewhat ecological approach with their *socio-technologies*, [5]—invoking the concept of organizing technology into three layers: 1) *physical objects* or *artifacts*; 2) *activities* or *processes*; and 3) what people *know* as well as what they do, [6] Bruno Latour posited the concept of the 'collective' to describe the networked association of humans and nonhumans. This network includes "microbes, electricity, atoms, stars… equations, automatons and robots… the unconscious and neurotransmitters”, [7] technologies, phenomena, and associated discourse.

Eric Kluitenberg also takes a similar stance in his reading of the relationship between humans and their use of personal technologies as forming an inhabitable, ecologically-based *environment*:

> Rather than an ‘object’, the technological infrastructures we inhabit have become environmental. They have become ‘spheres of life’ that we inhabit on a daily basis... the idea of ‘inhabiting’ technological ecologies emphasizes our connectedness to our environment (material, natural, technological) and our dependence on the resources available in that environment (material, energetic, biological, cultural)… These technological infrastructures… become ecologies in which social relationships are deployed, not just with other human beings, but also with other organisms and even inanimate objects. [8]

Artists today have increasing access to an extended range of creative materials and tools to draw upon, undoubtedly due to the reality that computer technologies are widely available through the consumer market and the subsequent development of progressively more user-friendly programming languages and computer software. Artists working independently or in interdisciplinary teams have the opportunity to vastly expand their skillset and approach to the creation of new work, often delving into areas previously associated with the sciences and engineering. According to Beatriz Da Costa,

> Rather than performing the role of an individual in search of a higher truth that will eventually be revealed and distributed to “the masses” in the form of paintings, sculptures, and other works, artists [are]… in the position to serve as interdisciplinary “experts”… skills such as software development and electronic board design, commonly associated with disciplines other than the arts—namely, computer science and engineering—have suddenly become part of the artistic tool kit… an artist able to design custom software is by no means a computer scientist, but he or she is able to learn that trade within a couple of years and integrate it almost immediately into artistic production and other projects… even without formal training, artists have gained sophisticated enough knowledge to build their

> own electronic boards and implementations in an effort to design devices that will serve their particular needs. [9]

Works positioned at the intersection of art/science/technology in no way replace scientific research, but rather serve to create active information pathways between practitioners from varying research disciplines (the arts, humanities, the sciences to name but a few), craftspeople, designers, and the general public. Extending Kluitenberg's above assertion regarding technologies as forming an inhabitable, ecologically-based *environment* into the realm of art making, artists/curators/writers Armin Medosch and Rasa Smite have helped to formally introduce the concept of a 'techno-ecological' approach as a key direction in contemporary artistic discourse:

> A 'techno-ecological' perspective [can be defined] whereby new artistic practices are discussed that combine ecological, social, scientific and artistic inquiries… offer[ing] a new perspective that sees art as a catalyst for change and transformation… techno-ecological perspectives have become now (sic) one of the key directions in contemporary discourses and are part of a larger paradigm shift from new media to post- media art. A range of practices which were once subsumed under terms such as media art, digital art, art and technology or art and science, have experienced such growth and diversification that no single term can work as a label any more. Traditionally separated domains are brought together to become contextual seedbeds for ideas and practices that aim to overcome the crisis of the present and to invent new avenues for future developments. [10]

It is clear that Smite and Medosch are carrying the concepts put forward by Latour et al. above to include present-day art making practices. Their notion of the 'contextual seedbeds' inherent to the development of an interdisciplinary-based art work serves to further foster the development of discourse around new artistic praxes—subsequently changing the role of artists, their subject matter, as well as the requisite tool kit involved in the task of artistic production. Techno-ecological perspectives position art as a powerful catalytic agent toward further lessening the "Great Divides" between ecological, social, scientific, artistic inquiry, and beyond.

CONTEXTUALIZING COMPOSING [DE]COMPOSITION AS TECHNO-ECOLOGY

Why Compost?

The choice of compost as a site for exploration stems from a personal 20-year practice of daily food-waste composting in various internationally based sites. An eventual turn toward the deep integration of this somewhat mundane environmental process into my artistic practice first began during a two-year residency at the Indonesian Art Conservatory in Yogyakarta, Java, where I began merging seeds sprouting from my garden compost pile into textile hangings and site-specific installation work. Whereas this previous work integrated plant life borne out of personal food refuse, *Composing [De]Composition* began an investigation into the actual process of decomposition and harnessed its incalescent properties for the generation of sonification art and music.

Seemingly spontaneously generated out of lifeless vegetal matter, the biota of compost self-organizes in any place there is a scrap of organic (i.e. carbon-based) matter, moisture and a source of oxygen. My very use of the word 'biota' underlines the fact that the decomposing mass is a living micro-ecosystem and invokes Bennett's notion of vital materialism. The biota is a living network of interactions between my family, the food we eat, and the environment we live in.

The main observable parameter driving the project is the biota's incalescence—the heat generated by the composting process. Temperature changes observed in the compost are caused by decomposition, which is a physical, biological and a chemical activity simultaneously supporting a myriad of life forms consuming the organic matter and subsequently enabling the bioavailability of macronutrients to the soil. While the perceivably silent activity of decomposition is brought into the physical range of human hearing through temperature data sonification, the project also establishes compost as an "actant … a source of action that … has sufficient coherence to make a difference" [11] in the creation of the work itself. As such, recontextualizing the product of home composting into an artistic material, a muse, and most importantly a collaborator. Through this recontextualized role, the material/textile/biota of compost is revealed as true energetic force of creation. Working with the biota is working at the edge of life and death—what is produced at the end of the human food chain continues on to support millions of smaller life forms who live, eat, reproduce, are eaten, and die at a timescale of a few days or a few months at most—a process transforming nearly everything into nourishment for future plant life.

While strategies for real-time compost temperature audification focused primarily on the development of sensing methods and sound-mapping strategies in the year leading up to the exhibition period, [‡‡] the opportunity to develop the project at a public venue also challenged me in my role as an artist/educator to engage exhibition visitors on many levels. Simply walking around *Composing [De]Composition's* sonic and visually information-rich research laboratory invited visitors to better grasp the complex ecology

[‡‡] A deeper discussion of sound-mapping strategies used this stage of the data sonification project can be found in Parker, Jennifer. "Sonification as Art: Developing Praxis for Audifying Compost". In *Proceedings of the 21st International Conference on Auditory Display (ICAD 2015)*. Edited by Katharina Vogt, Andreopoulou, A. and Goudarzi, V. Graz (KUG), Austria (2015): Institute of Electronic Music and Acoustics (IEM), University of Music and Performing Arts. 157-164.

of the decomposing heterogeneous mass, but also was an attempt to inspire them to consider trying home composting—via the novel act of listening to compost temperature datasets. It was my full intent to illustrate to visitors how home composting offers anyone who eats a straightforward, daily way to actively participate in the overall reduction of methane emissions—which in turn can have a concrete impact on the larger issue of climate change.

Contextual Seedbeds: Mind Mapping Composing [De]Composition

As noted above, sonification research already involves a complex, interdisciplinary approach toward its realization. Using the framework of a mind-map, the following section unravels the various aspects of the techno-ecological artistic praxis involved in the development of *Composing [De] Composition*. Here, individual conceptual seedbeds involved in the development of the project are introduced along with a brief explanation on how they are interwoven together.

Figure 2.1 below is a visualization of the basic techno-ecology that evolved in the creation of *C[D]C.* Drawing upon Latour's notion of collective introduced above, the nonhuman collective members of the project include the actant compost and its network of microbes, fungi, and bacteria, the materialities of sound, electronics, and data, the resultant audio display, as well as the discourse created around the topics of Sustainability and agency/DIY (Do It Yourself). Using Smite and Medosch's premise of contextual seedbeds, the observation of compost and the various processes involved in the sonification of its changing temperatures are situated into six primary 'contextual seedbeds': Compost, Data, Art, Sustainability, Electronics, and DIY. These seedbeds are

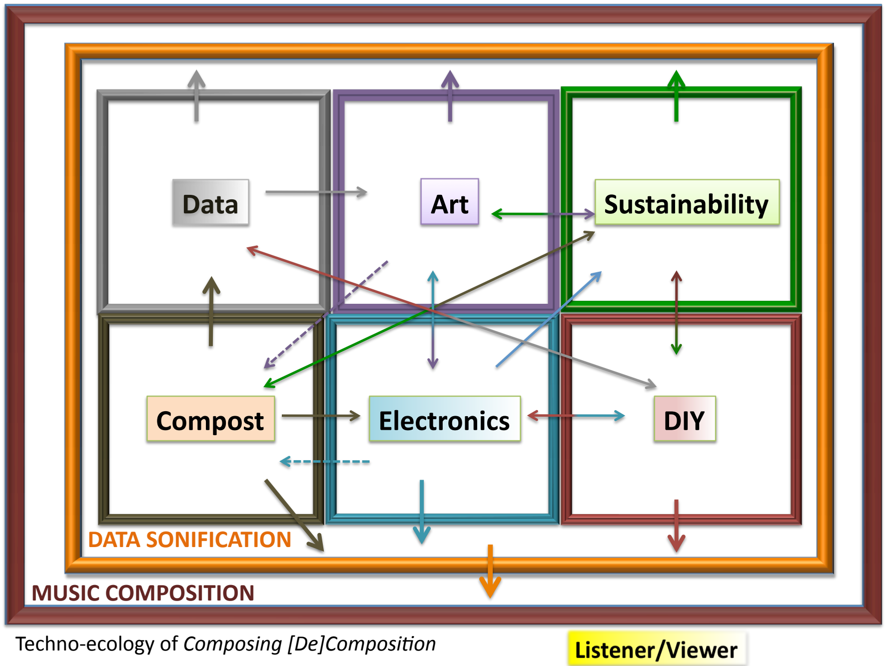


Figure 2.1. Top level techno-ecology of *Composing [De]Composition.*

then placed within the larger, enclosing frameworks of data sonification and music composition. Figure 2.1 also shows directional arrows pointing outside and between the boxes to indicate my thinking on how the different "seeds" inform and relate to the others, hence forming a successful techno-ecology.

As it was my aim to empower and inspire audiences with new knowledge regarding compost and its life force rather than to mystify, I saw it as my responsibility as an artist and educator to convey as many as possible of the ideas contained within the contextual seedbeds and the relationships between them to the listener/viewer in the finished work. Figure 2.1 neatly illustrates Smite and Smits' statement that

> Emerging "techno-ecological" art practices often act as connectors—they are crossing and bridging different fields, societal groups, human and non-human worlds, whereas their artistic language is the key factor and the 'short-cut' that

> helps to establish a dialogue with society, to reach its consciousness and to create feedback with it. [12]

The six equally-sized subject containers fitting inside two larger contextual seedbeds labeled Data Sonification and Music Composition reflect the idea that all seedbeds are equally necessary ingredients in realizing my vision of the work as a whole. The positioning of the Data Sonification seedbed inside of the larger, Music Composition seedbed also reveals my stance in relation to using data as an artistic medium as both a composer and as a sonification artist.

It is my belief that both tactics can be employed to communicate aspects of a dataset to different ends. For example, whereas the end aim of sonification is to communicate chosen datasets in a sonically comprehensible way to listeners, the use of data to generate a music composition need not have the same strict purpose. In my view, while both the composer and sonification designer examine and interpret data (through using it to generate pitch materials, gestural information, and/or rhythmic groupings/patterns, etc.) to express the system studied, the composer of data-derived music has much more agency in her creative decision-making, often being driven toward the objective of transmitting personal musical style or tastes to listeners. It is for this reason that sonification and music composition exist as two separate seedbeds.

For example, the composer may choose to interpret changes in a dataset very strictly and literally as a way to generate pitch materials and groupings—using Hertz, or chromatic and/or microtonal scales. Conversely, she may instead perhaps decide to use the same data to govern relationships between pitches within a culturally-codified musical scaling system. Whereas the first compositional tactic above aligns very closely with the aims of data sonification and affords listeners a baseline from which to comprehend the data and intrinsic changes within, it is my opinion that the second strategy sacrifices accuracy in presenting the data based on instrumentation, the composer's aesthetic preferences, a desire for the work to sound "musical" to listeners, or through prioritization of culturally-specific musical knowledge and associations. A more detailed discussion of my findings on deploying a dataset within the contexts of real-time audification and sonifcation is found in Chapter 3, while a discussion on musification versus sonification of the same dataset is found in Chapter 4.

Inside the Seedbeds

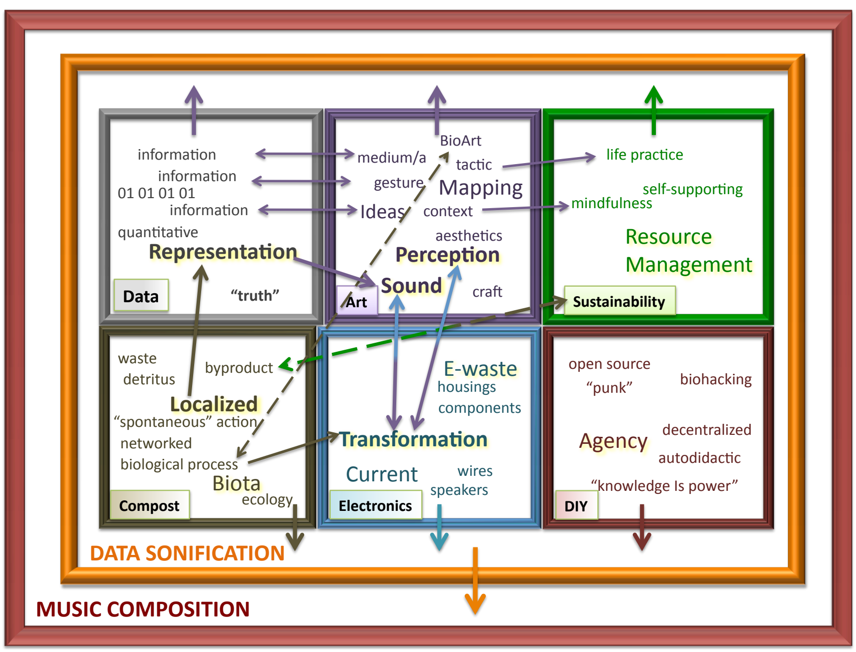


Figure 2.2 Second level view of *Composing [De]Composition's* techno-ecology reveals deeper ideas held in reference to each of the six conceptual seedbeds. Arrows indicate pathways of how the Compost, Data, Art and Electronics seedbeds are interconnected. Overarching ideas are shown in large-sized font, while directional arrows show the flow of ideas between seedbeds.

Figure 2.2 reveals the deeper implications contained within each of the contextual containers set out in Figure 2.1. As illustrated, each seedbed consists of many different ideas, or seeds, and has at least one and often two overarching concepts that are more prominently considered (represented as words in a larger font size). For example, the reader will see that the seedbed labeled 'Compost' includes keywords as to why the material was chosen—such as *spontaneous action*, *biological process*, *Biota*, *ecology* and *waste*—many of which have been discussed earlier in this chapter. Other terms such as *byproduct*, *detrius* and *networked* are additional factors in my thinking on the subject. The reader will also notice that the term *Localized* appears with *Biota* as a larger concept in the seedbed. One of the main characteristics of the biota is its non-homogeneous nature—that is to say, temperature changes occurring in one area of the mass may not be directly related to those in another area—thus, temperature changes in the pile manifest as *highly localized*, rather than global.

Zooming out again on Figure 2.2, I redirect the reader to the grey Data seedbed. Here, seeds describe data primarily as a representative medium—"an abstraction from some source." [13] Hence, the overarching concept addressed in the seedbed is that sonified data is an abstract *representation* of the biota—because of this, the concept/seed is shown as larger in size than the other descriptors inside the seedbed. Because the collected datasets can never truly represent the entirety of the biota, nor give a complete picture as to all of the temperature related changes occurring in it, it is therefore important to recognize that "data sonification *works with the data, not the object abstracted into* *data*". [14] The arrow pointing from the Compost seedbed into the Data seedbed serves to symbolize this point.

Terms included in the Data seedbed are *"truth," quantitative*, *information*, and *01010101*. As mentioned above, data sonification is an abstract representation of the biota. I include the term *'truth'* inside the data seedbed as I consider the idea that collected data on a subject can symbolize a window into some sort of absolute about it. For example, in the case of *Composing [De]Composition*, the data generated on the minute-by-minute temperature readings in the eight areas of the biota verify the continuous activity levels of the microbial actants contained within.

While all data collected from the biota is *quantitive information*, there is yet another intricate yet 'invisible' actant supporting the techno-ecology—my computer's central processing unit. The inclusion of binary code (01010101) as a conceptual seed in the Data seedbed is meant to demonstrate the complex relationship that data has to its source. 0101010 represents the *visual equivalent* of machine-readable binary code for the ASCI character "U". The patterns of ones and zeroes understood by humans as binary code serve only as a *visual representation* of the patterned signal 'on'/1 //signal 'off'/0 messages understood by the CPU for the interpretation of ASCI. Data does not exist in a vacuum—it stems from materiality and needs materiality for its interpretation. Here, I call up the vital materialism that exists between the biota, temperature sensors, electrical impulses and connections, the mictrocontroller, computer coding, operating system, CPU, etc. involved in the conversion and translation of the biota's energy into data.

Connecting the Seeds

Following arrows interconnecting seeds between seedbeds, the reader embarks on a conceptual chain reaction of sorts, tracing my thinking processes on how data can be rendered as sound via the medium of sonification art. For example, the double-terminated arrows in Figure 2.1 between the *information* seeds in the Data seedbed leading into various seeds placed inside the Art seedbed indicate my conceptualization of data's role in the project as an artistic *medium*, and how detected patterns contained within the data form sonic *gestures*. Similarly, the use of data is what actually enables the sonification, thus an arrow points directly out of the Data seedbed into the larger, encompassing Data Sonification seedbed.

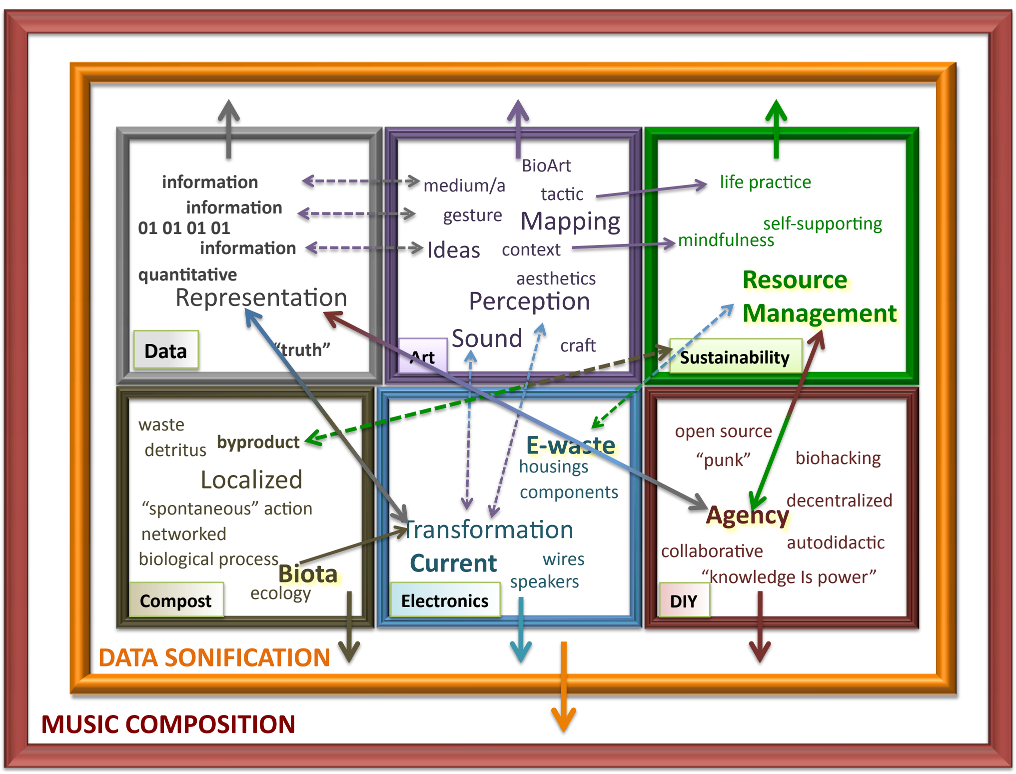


Figure 2.3: Conceptual Network 2. Arrows reveal conceptual networks interconnecting the Data, Sustainability and DIY seedbeds.

Following the various chain reactions of arrows between conceptual containers illustrates the different conceptual networks at play. For example, an arrow moves directly up and outward from the *Localized* seed in the Compost seedbed to the *Representation* seed in the Data seedbed, then out toward to *Sound* seed in the Art seedbed. It then moves next to the *Transformation* seed in the Electronics seedbed before bouncing back again to the *Perception* seed Art in the seedbed. Hence, this conceptual chain reaction infers that localized temperature changes in the biota's radiant energy are first *represented* as data and then *transformed* into humanly *perceivable sound* by the electronics of the audio display.

A second conceptual network that results from interconnections in my thinking in relation to the Compost, Sustainability and DIY seedbeds is shown in Figure 2.3. Here, the reader will see that the *Biota* seed in the Compost seedbed is linked to the DIY seedbed's concept of *Agency* by a network of double-terminated arrows connecting the Compost, Electronics, and Data seedbeds. Thus, this network infers that through harnessing the microorganisms' thermal energy and transforming it into sound, the biota exercises agency/can be expressed/is expressive in the work.

As sustainability and the do-it-yourself ethic are recurring themes running through the entire body of my artistic work, the final two seedbeds—Sustainability and DIY—serve to bookend the project as a whole. The Sustainability seedbed includes the seeds of *life-practice*, *resource management*, and *mindfulness* and communicates my ethical beliefs as an individual living in an age of dwindling natural resources. The DIY seedbed expresses the autodidactic nature of the project, my desire to help others understand the rich process of composting, as well as my somewhat decentralized role in generating the actual values contained in the dataset.

Conclusion: Sustainable Futures

The choice to generate and collect data and create public art from personal compost evinces my desire as an artist/educator to highlight to the greater community how easy it is to increase one's own day-to-day sustainability efforts through a direct, 'do-it-yourself' method of personal resource management. Rather than depending on a dataset that reflects connection to government or a corporately-controlled space and science program, I chose to concentrate on an equally important, large, multi-agential system that originates from a far more personalized source. This attitude reflects the issues of sustainabiility and the DIY ethic, and also directly speaks to Medosch's call for the development of more sustainable practices in the use of technology:

> The instrumentalization of science and technology for economic gain and military needs has to be met to with creative and imaginative uses of technology that answer the urgent need of societies (sic) [at-large]. [15]

Sonification of the biota, paired with the open BioArt laboratory approach, weekly public gallery talks and a Data Listening Session transformed a normally silent art gallery environment into an intimate public space. The techno-ecology of *Composing [De]Composition* attests to Latour's attitude that,

> Sciences and technologies are remarkable… because they multiply the nonhumans enrolled in the manufacturing of collectives and because they make the community we form with these beings [and each other] a more intimate one. [16]

Filling the space with the 'voices' of the biota sparked public discourse within my local community on composting, the physics of sound, sustainability, biology and hopefully inspired people to try backyard composting.

After experiencing the public data listening session, UC Riverside ethnomusicology professor, Rene Lysloff remarked,

> For me, your work is extraordinarily important in raising public awareness of environmental processes that are basic to human survival. Hearing the very real processes behind organic decomposition and soil production compels us to think deeply about our fragile ecology in all its complexity. [17]

"Thinking about our fragile ecology in all its complexity" is indeed is an urgent need for today's society. It is my hope that in creating a perceivable 'voice' for the biota—in the interest of facilitating/reconfirming the intimacy of our collective link with it—visitors came away from their gallery experience with a mindful realization: the importance of their agentive role even in mundane, day-to-day decisions such as where to toss their empty banana peels.

<u>Notes</u>

1) Jane Bennett. *Vibrant Matter: A Political Ecology of Things* (Durham: Duke University Press, 2011), 115.
2) Ibid., 58.
3) Roberta Buiani. "Ecology and Sustainability in Art and Science". *Acoustic Space* 12 (May 2014): 69-70.
4) Ibid.
5) Wiebe E. Bijker, Thomas P. Huges, and Trevor Pinch. eds. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. (Cambridge: The MIT Press, 1987), xx.
6) Ibid., xiii.
7) Bruno Latour. *We Have Never Been Modern* trans. Catherine Porter. (Cambridge, MA, Harvester Wheatsheaf, 1993), 109.
8) Eric Kluitenberg, "Techno-Ecologies: Inhabiting the Deep-Technological Spheres of Everyday Life". *Acoustic Space* 11 (2012): 9.

9) Beatriz da Costa. “Reaching the Limit: When Art becomes Science,” in *Tactical Biopolitics: Art, Activism and Technoscience*, eds. Beatriz da Costa and Kavita Philip (Cambridge, MA: The MIT Press, 2008), 368-370.
10) Rasa Smite and Armin Mendosch. “Introduction”. *Acoustic Space* 12 (May 2014): 6.
11) Jane Bennett. *Vibrant Matter: A Political Ecology of Things* (Durham: Duke University Press, 2011), iix.
12) Rasa Smite and Raitis Smits. “Emerging Techno-Ecological Art Practices—Towards Renewable Futures” *Acoustic Space* 11 (2012): 130.
13) Michael Filimowicz. “Piercing Fritz and Snow: An Aesthetic Field for Sonified Data”. *Organized Sound* 19 no. 1 (April 2014): 90-99.
14) Ibid.
15) Armin Medosch. “*Fields*—An Index of Possibilities”. *Acoustic Space* 12 (May 2014): 9.
16) Latour, *We Have Never Been Modern,* 108.
17) Rene Lysloff, personal communication, October 17, 2015.

CHAPTER 3: A DEEP DESCRIPTION OF *COMPOSING [DE]COMPOSITION*

Chapter three consists of a deep description of *Composing [De]Composition* divided roughly into three sections. Beginning with a general description of compost's biological and physical properties, I then go on to describe my experiences in conducting a 45-day compost temperature study outside of my home on the University of California, Riverside campus. The 45-day compost temperature study was not only crucial in answering questions regarding the numerical temperature range of the compost, but the process also teased out integral questions needing to be addressed in the design of the sensor interface. A brief statement on my initial strategies toward parameter mapping from temperature to sound to create the gallery's soundscape is also included. [§§] In addition, the study determined the most effective methodologies in measuring the compost's temperature as a whole, as well as provided essential information on developing the tools necessary to sonify it.

I conclude the chapter turning to a deep discussion of my findings after conducting a 113-day public indoor compost temperature data sonification research laboratory/BioArt exhibition at the University of California Riverside's *Sweeney Art Gallery.* Topics discussed in this section include: the design of the gallery-based research laboratory; various approaches toward parameter mapping for real-time audification, the development of earcons, and the resulting temperature-driven soundscape. Lastly, I

[§§] A more detailed discussion of this topic can be found in Parker, J. "Sonification as Art: Developing Praxis for Audifying Compost". In *Proceedings of the 21st International Conference on Auditory Display (ICAD 2015)*. Edited by Katharina Vogt, Andreopoulou, A. and Goudarzi, V. Graz (KUG), Austria (2015): Institute of Electronic Music and Acoustics (IEM), University of Music and Performing Arts. 157-164.

present my conclusions/observations on the results of a public Data Listening Session held at the end of the gallery-based research period.

COMPOST

The Biophysical/Multi-agential Aspects of Compost

Briefly, composting is a complex biological process that occurs when insects, invertebrates and microorganisms "digest" the carbon of the carbohydrates contained in decomposing organic matter. The terms "compost" and "biota" in the context of this project refer to the entire network of agents present during the decomposition process—consisting of decaying vegetal matter, worms, large insects, fungi, and millions of microorganisms. Although decomposition occurs at both the aerobic and anaerobic levels, the type of decomposition employed by *Composing [De]Composition* is on a small scale and aerobic in nature—indicating that the organisms involved in this process require oxygen and moisture to live and reproduce—while anaerobic decomposition most commonly occurs at the industrial level.

As part and parcel of the carbon- and oxygen-rich "feeding frenzy" of decomposition, the various-sized organisms involved also generate heat, water vapor and carbon dioxide during the process of respiration. Common insects found in a compost heap include: fruit flies, ants, earwigs, and black fly larvae, to name but a few. These larger beings can all be seen clearly without magnification. Microorganisms such as fungi and actinomycetes (bacteria that resemble fungi) occur in the outer 10-15 centimeters of a compost pile are also visible to the naked eye. Under 200x magnification, white potworms, and tiny insects such as springtails and mites can be seen in action.

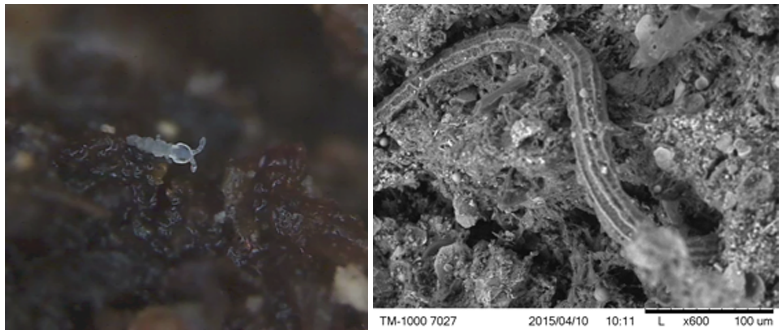


Figure 3.1: Compost springtail at 200x magnification (l);
a bacteria-eating nematode at 600x (r).

Zooming to 400x magnification, larger bacteria—which make up 80-90% of the microbial community found in compost—are visible and the micro-structure of fungi can be more closely examined. Figures 3.1 and 3.2 show members of the compost ecosystem at varying magnification levels. As metioned above, there are two main types of composting—backyard composting and thermophilic (heat-loving) composting that occurs at the industrial level. In optimized industrial situations, the life of a compost pile is roughly a few months until the “curing phase”. This occurs when the oxygen supply is no longer available to the ecosystem, and the compost becomes a sterile market-ready mulch. The temporal range for backyard composting on the other hand has a much

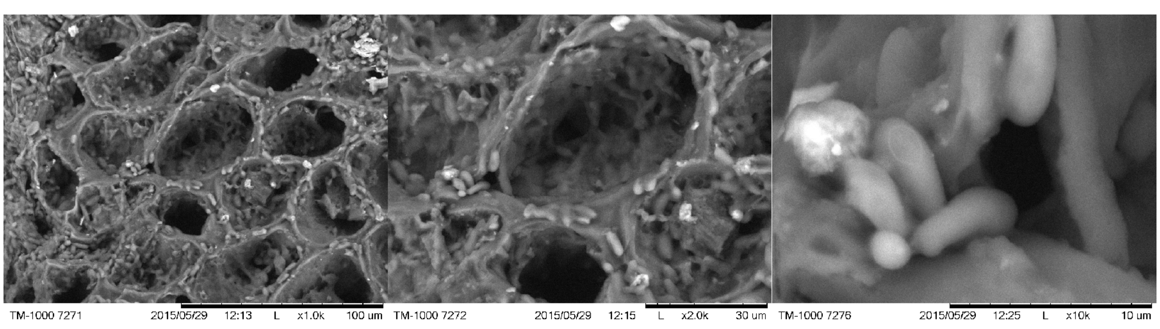


Figure 3.2: Scanning electron microscopy of a decomposing mango skin at varying zoom levels (100x, 2000x, and 10,000x from left to right) reveals an ecosystem teeming with light colored, rod-shaped bacteria.

broader spectrum, as home composting occurs on a much smaller scale and most commonly in closed containers for efficiency and matters of public health/city ordinances. In this type of composting, new matter is constantly added to the larger pile/bin and decomposition speed completely depends on the methodology used. Turning the pile every day is the most effective technique to make sure oxygen is supplied to the entire biota on a regular basis, helping to speed along the composting process.[2]

Decoding the Biological Process that Best Represents Decomposition

Using compost as artistic grist involved a revelatory process of decoding *which* aspects of the heterogeneous mass best represent it as a whole. At the temporal and geometric scale of human visual perception, compost appears to be in stasis. Daily observation of the biota over the period of weeks is required to see color and texture changes. Microscopic study of compost shows the opposite—a hugely dynamic, unstable ecosystem with a large amount of activity among a complex array of life forms.

Oxygen and water must be present for aerobic decomposition to be enabled. Monitoring changing moisture levels during decomposition is a simple and easily available way to detect changes in the biota. **"**If adequately aerated, composting material with moisture content between 30% and 100% will be aerobic". [3] Obtaining accurate, biota specific oxygen levels, however, would require a laboratory-like closed system designed to supply enough oxygen to maintain the pile while also monitoring it for a total decrease in oxygen as the biota returned carbon dioxide in the respiration process. Constructing this type of setup would be difficult and too complicated for the purposes of this study.

On the macroscopic scale, compost can be thought of as a site of oxidation of organic compounds. Oxidation stabilizes these compounds making them available for use as a soil supplement for future plant propagation. Carbon in the form of carbohydrates is one of the main ways the organisms get energy, and the nutrients made available by the biota most important to improving soil health include nitrogen, phosphorus, and potassium (referred to as 'NPK' forthwith).

Monitoring the levels of NPK produced by the biota also presented its own set of drawbacks. Current affordable soil nutrient testing is not sensor-based. Rather, the technology requires that a small sample be removed from its context and placed in an aqueous solution—a process that only to obtains approximate levels (i.e. high, medium, and low). I decided that this system was too cumbersome and inexact to be of interest. In addition, components such as carbon (in the form of carbohydrates), potassium, nitrogen and phosphorus represent inputs and outputs to and from the system and do not well represent the decomposition process itself.

Contrastingly, decomposition and temperature are tightly coupled. Heat accelerates microbial functions and also acts to change the microbial ecology, and the efficiency of the composting process doubles for every 50˚F increase in temperature. There are two temperature dependent, yet distinct stages of the composting cycle: 1) The "active" stage which itself has two phases; and 2) The curing stage. The "active" stage of composting occurs between 32˚ and 149˚F. When the pile is at temperatures between 32-104˚, mesophilic bacteria predominate. Backyard composting operations remain at this stage unless there is a multi-container setup where no new vegetal material is added to one of the containers, allowing the compost to steadily increase in temperature. Above 104˚F, the mesophiles begin to die off and thermophilic bacteria take center stage. These microbes can survive in temperatures up to 155˚F. Pathogens and seeds in the compost pile are terminated when the pile reaches levels of 131˚F. Above 160˚F thermophilic bacteria die-off begins, and the compost becomes sterile. Temperatures decrease when when oxygen is no longer supplied signaling the final stage of the compost cycle.

SENSING

Prototyping the Temperature Sensing Apparatus

As a precursor to the development of the project's sensor apparatus, a handwritten account of daily compost temperatures was recorded for a period of 45 days between December 8, 2014 and January 21, 2015. The composting container used for the study was located outside my home on the UC Riverside campus (Figure 3.3). The compost bin used was a rotating, barrel-shaped ventilated plastic container suspended on a metal stand, with two light brown lids located on the top and bottom of the barrel. One of these lids is removed to add more vegetal matter to the composter.

Over the course of the prototyping period, the number of regions monitored for changes in temperature rose in total from one to eight as the tools of data collection became more refined. At first, an analog meat thermometer was used, but it was difficult to achieve accuracy with it. Next, a four-inch digital meat thermometer was substituted. Its improved accuracy and relatively instantaneous speed afforded the ability to divide the compost bin into four equal quadrants, and record a distinct compost reading from each zone in a relatively short time period.

Figure 3.3: Aerating the compost outside my home on the UCR Campus.

The temperature data collected during the 45-day period is visualized graphically in Figure 3.4 below, with the horizontal axis representing each day of the study (1-45) and the vertical axis as temperature in degrees Fahrenheit (0-110). The lowest temperature of the day was sourced online and is illustrated as the bottom blue line, while the outside temperature at the time of the compost readings is plotted as the strong black line. Figure 3.4 also illustrates the temporal trajectory in my process of learning how to read the compost with increased accuracy. The increasing collection of temperature data underwrites my recognition of the biota as a dynamic homogeneity rather than as a fixed mass.

The singular green line spanning from day 1-27 shows one temperature reading representative of the entire pile—a direct result of the inadequacy of my temperature reading tool. At day 28, the digital thermometer was first employed.   The tool's increased ccuracy enabled quick temperature readings from multiple areas within the span of a few a minutes. With faster and more accurate temperature sensing, I realized

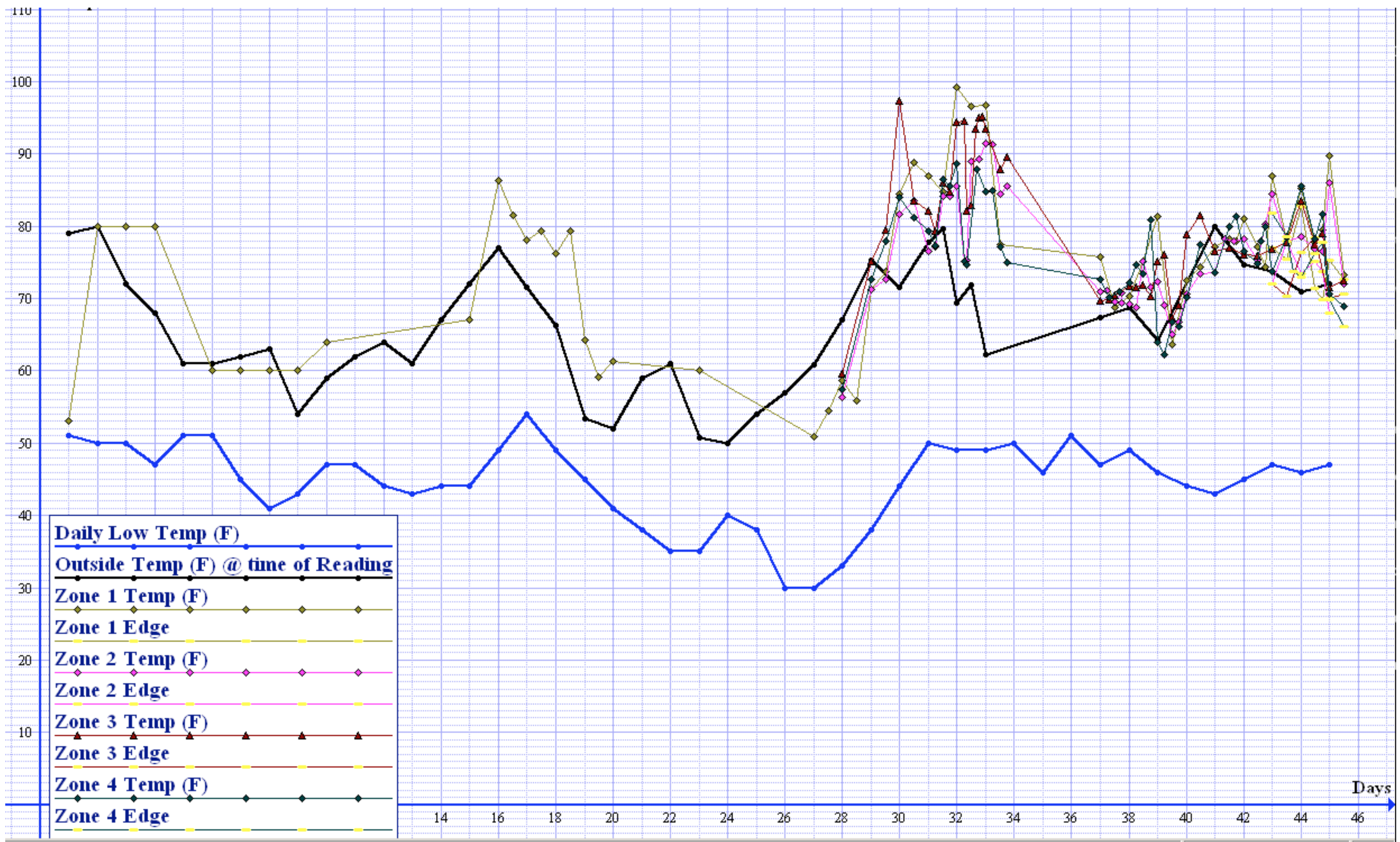


Figure 3.4: Compost temperatures juxtaposed against daily high (black line) and low (blue line) temperatures over a period of 45 days. The temperature sensing apparatus is first used at day 28, showing multiple temperature readings.

that I should also begin to monitor the biota both pre- and post aeration. Therefore, beginning at day 29, the pile was monitored both before and after fully turning it four to five times—yielding two different temperature readings per day. Rapid temperature changes were recorded immediately after turning the pile as the act of turning the compost triggered a race toward temperature equilibrium throughout the biota.

The increased amount of information is reflected on the graph by inclusion of multiple points for each day. There is no attempt to give the multiple readings an accurate temporal value in the graph timeline, instead, the points divide the day into roughly equal segments. At day 43, it is observed that there is a large difference in temperature at the most extreme areas of the quadrants themselves. Readings taken at the center of the compost bin were almost consistently ten degrees higher than readings taken at the outer edges of the bin. This convinced me that at least eight temperatures (two per zone) should be recorded at any given time.

During this initial research stage, the necessity of designing an array-based temperature sensing apparatus was made absolutely clear, in order to reflect the non-homogenous character of compost. Conclusions reached at the end of the temperature observation period include:

1. Given the heterogeneous character of the compost itself, the deployment of sensors inside of it can only detect the conditions in localized areas at a given moment in time;

2. In order to monitor the biota as more of a “whole” phenomenon at any given moment, the sensing apparatus must be able to measure multiple zones simultaneously. The ability to simultaneously measure eight temperature “zones”—including points at the compost’s edges and its core—is enough to produce a basic profile of the pile;

3. Temperature fluctuations observed immediately after aerating the pile can be measured and audified to produce interesting results.

On Sensing Decomposition: Protoyping Compostable Sensors

The process of working so closely with the biota also raised the question of how to sense the process of decomposition itself. To answer this question, a series of biodegradable paper sensor prototypes were developed in the hopes of integrating them into the larger sonification. It was postulated that as the paper backing of a sensor decomposed, the pathway of the conductive part of the sensor would also be broken down, causing the resistance of the sensor to increase.

The compostability of a silver nano-particle (Ag- NP) circuit ink-jet printed directly onto photo paper and placed directly inside the compost bin was first observed (Figure 3.5). Initial tests showed successful decomposition was achieved after 24 hours inside the biota. However after close inspection, it was realized that the tiny fractures in the Ag-NP ink were most likely created by the rough texture of the composting material scraping the sensor upon removal from it, and not by decomposition. Another large concern that arose during this part of the study was the fact that the laminate used on the photo paper remained inside the

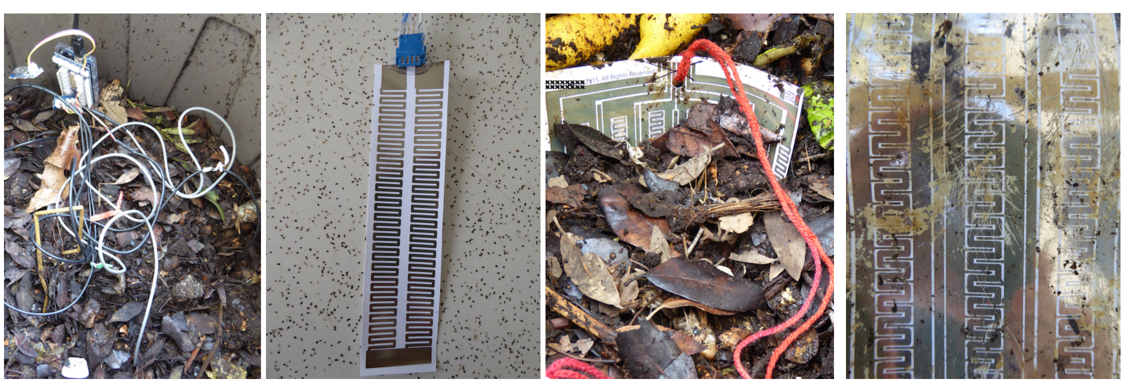


Figure 3.5: The sensing prototype (left), a paper Ag-NP sensor design (c. left, © Adrian Freed 2015), the Ag-NP prototype buried in the compost bin (c. right). Scratches on the sensor's surface proved that the biota's rough texture was not suitable for this design (right).

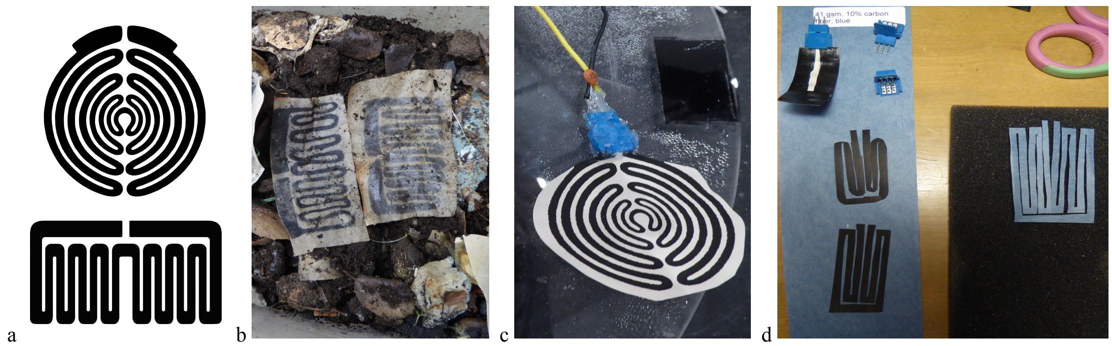


Figure 3.6: (a) Two silkscreen designs (©no.e Parker and Adrian Freed, 2015); (b) hand drawn graphite and charcoal pencils on newsprint; (c) a silkscreened sensor (conductive ink on newsprint) with electronics; and (d) hand made sensors using conductive paint/newsprint (top left) and cut out of various conductive papers.

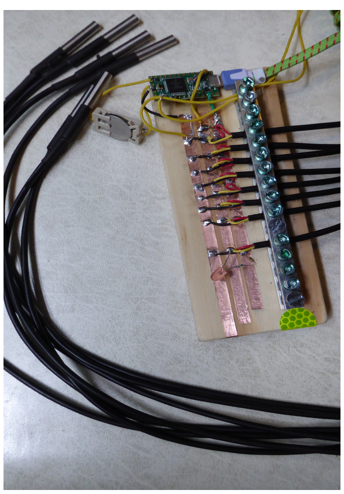
biota as a non-compostable residue. Because of these reasons, research of the inkjet silver nanoparticle sensor was abandoned.

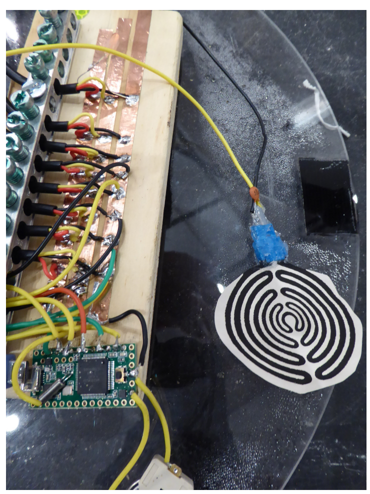
Figure 3.6 shows alternative paper sensor prototypes still in development. Various trials were conducted in creating compostable sensors with different conductive materials and fabrication techniques such as: hand-cut from conductive paper, hand-drawn onto newsprint with charcoal and graphite pencils, and conductive ink hand silkscreened onto leaves, newsprint, edible wonton wrappers, and sheets of seaweed. The silkscreen/conductive ink approach showed the most promise as many sensors could be produced from one screen.

The Sensing Apparatus

Figure 3.7 shows Freed's design for the project's temperature sensing apparatus. The final version of the device was built (by me) during an extended research period at *CNMAT*. Freed programmed the microcontroller using Arduino software so that a serial byte stream of SLIP-wrapped Open Sound Control bundles could be sent via USB into the MAX/MSP programming environment. [***]

The array-based device consists of an Arduino Teensy 3.1 microcontroller connected to eight Dallas Onewire temperature sensors, five additional terminals to continue prototyping the abovementioned paper sensors, and a battery-powered real-time clock (RTC). The Arduino code assigns each temperature sensor number an OSC address, reading its values and temperatures while tagging it with the date and time recorded by the onboard RTC, bundling and printing the information into Open Sound Control packets. "OSC bundles allow OSC messages to be grouped together to preserve the order and completeness of related messages." [†††] All this tagged and bundled data is then sent via the SLIP stream to be read and used in the MAX/MSP *o.dot* environment (also designed by Freed) for sonfication.

a. 

b. 

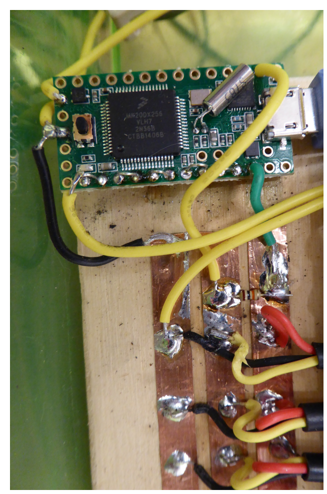
c. 

Figure 3.7: The temperature sensing apparatus with (a) Dallas Onewire thermocouplers and two RTCs (battery-powered and crystal) ; (b) compostable paper sensor, and (c) the ArduinoTeensy 3.1 microcontroller (Note: Paper sensors are not yet attached to microcontroller terminals in image (c). Image(c) also details the Teensy's rod-shaped crystal RTC.

[***] https://github.com/CNMAT/OSC

[†††] Freed, A (2015). *Compost AsOC source code* (Ardiuno version 1.0.6) [Source code]. https://github.com/CNMAT/OSC.

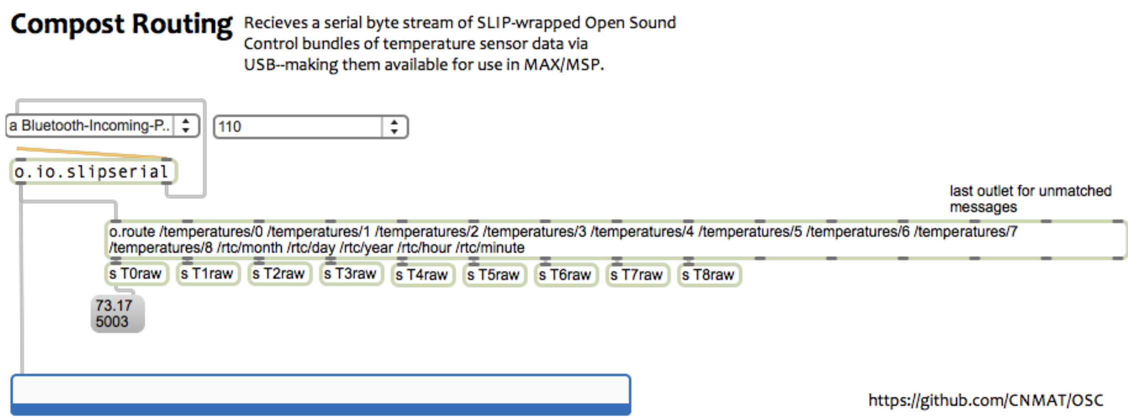


Figure 3.8: *CompostRouting* is the OSCforArduino MAX help patch modified for the *C[D]C* Arduino code.

Figure 3.8 shows the OSCforArduino MAX help patch modified with the names filled in for the values named in the *C[D]C* Arduino code. It accepts incoming time stamped OSC temperature data from the Teensy 3.1 microcontroller using the *o.io.slipserial* object and routes it to the main data sonification patch in real-time.

The Compostable Audio Display

The process of the creating the custom audio display was completed in three phases: testing, designing and building. The testing phase required investigation into different speaker housing materials and commercially available speakers/power amplifiers that would to satisfy four main objectives: maximal sound quality for a wide and varied frequency range, system portability, robust indoor/outdoor use, and biodegradability/reuseability. Table 3.1 below lists the components of the audio display. Auto and marine audio components were integrated into the final display due to portability and indoor/outdoor use requirements. In addition, a robust power amplifier was required as the audio display would not be turned off for the entire research period.

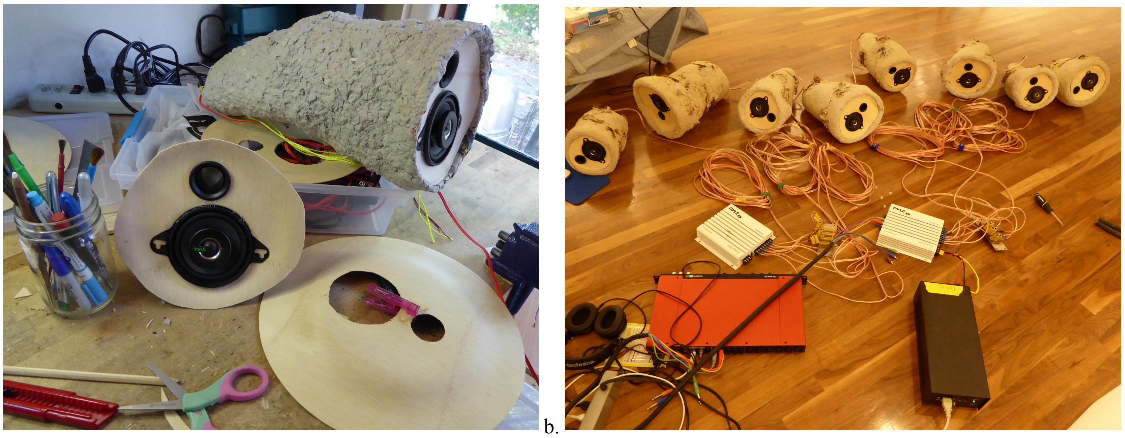
Table 3.1

Composing [De]Composition Audio Display Components	
2	4-channel Pyle PLMR 400 watt marine waterproof amplifiers
8	Pyle Wave PLX32 3 ½" automotive speakers
1	ASTEC 12v 24A regulated power supply
	Focusrite Scarlett 18i-20 USB audio interface
1	Mac Mini computer

I have made a conscious effort toward achieving a sustainable sound-art practice. Sourcing materials from quickly renewable and reusable resources was a key factor in the overall design of the audio display. Although electronic audio components are not quickly biodegradable in any sense, they are fully reuseable for future data sonification research/art projects.

Figure 3.9 shows: (a) the process of speaker building at the CNMAT electronics lab; and (b) the audio display components before final installation at the gallery. Moreover, the organically-shaped conical speaker housings are fully biodegradable—consisting of paper pulp formed over a base of wire and fine metal mesh. [‡‡‡] Speaker baffles—increasing the resonance inside the speaker chamber while also holding the speakers and plastic ports in place—were hand cut from bamboo picnic plates. The choice of lightweight and strong materials such as paper and bamboo also contributed greatly to the portability of the setup. It is my hope to continue refining my design until it is 100% self-powered by solar panels and microbe batteries. This would allow greater freedom in conducting compost and soil temperature research in remote areas.

‡‡‡ Repurposed from University of California Riverside and Berkeley campus newspapers and Riverside area local supermarket flyers.



a. b.

Figure 3.9: (a) Speaker building at UC Berkeley's Center for New Music and Audio Technologies. Biodegradable bamboo plates were cut and used as speaker baffles. (b) The audio display setup before final installation at the UCR *Sweeney Art Gallery.*

SITE ONE: AN OUTDOOR COMPOST TEMPERATURE STUDY

Paramter Mapping for the 45-Day Outdoor Study

The primary challenge inherent in sonification art—this work included—is for the artist to develop creative and meaningful sonic metaphors for the expression of processes beyond the scale of human perception. Lakoff and Johnson state, "The essence of metaphor is understanding and experiencing one kind of thing in terms of another." [4] Similarly, Walker and Nees stress that sonification "seeks to translate relationships in data or information into sounds(s) that exploit the auditory perceptual abilities of human beings such that the data relationships are comprehensible" .[5] Therefore, it is imperative to form a robust, audible metaphor that will successfully carry the audience into the unseen data-world of compost temperature.

In the following section, I discuss my aesthetic choice of using a direct, linear mapping of the compost temperatures to Hertz. Figure 3.4 above illustrates that the temperature of the compost ranged between 55˚ and 99.2˚F. When directly translated into frequency, these values fall neatly into the bass register of the audible range of human hearing. Ergo, a direct, linear mapping of the biota's temperature profile to frequency was an intuitive design choice, and I feel that direct translation of temperature to frequency using a linear mapping keeps the data closest to its original form. My strategy of using pure frequencies to depict temperature also prevents the audification from sounding overtly musical.

The parameter mapping initally developed to real-time audify the biota's temperature data consisted of an eight partial wavetable. Partials of the wavetable were determined by each temperature sensor's data. This created a dynamic and self-modifying wavetable allowing the thermo-physical processes of the biota (not at all running at audio rate) to generate the sound profile of the audio itself. [6]

Samolov has confirmed that human hearing "in the range below 500 Hz… detects differences of approximately 1 Hz, while in the range above 500 Hz, the perceptibility range may be roughly described by a relation of 0.002 *f*". [9] Close temperature differences between zones—oftentimes in the range tenths of degrees—in the biota also produced acoustic beating. These two factors combined created a very visceral and active soundscape experience—turning the possibility of having two or more sensors with data readings in an extremely close range into a dynamic, sono-textural advantage.

Figure 3.10 below shows a sonogram of the original audification mapping. The darker, orange-colored areas inside the individual yellow horizontal bands of the sonograms illustrate the acoustic beating, indicating wave convolution. A more detailed

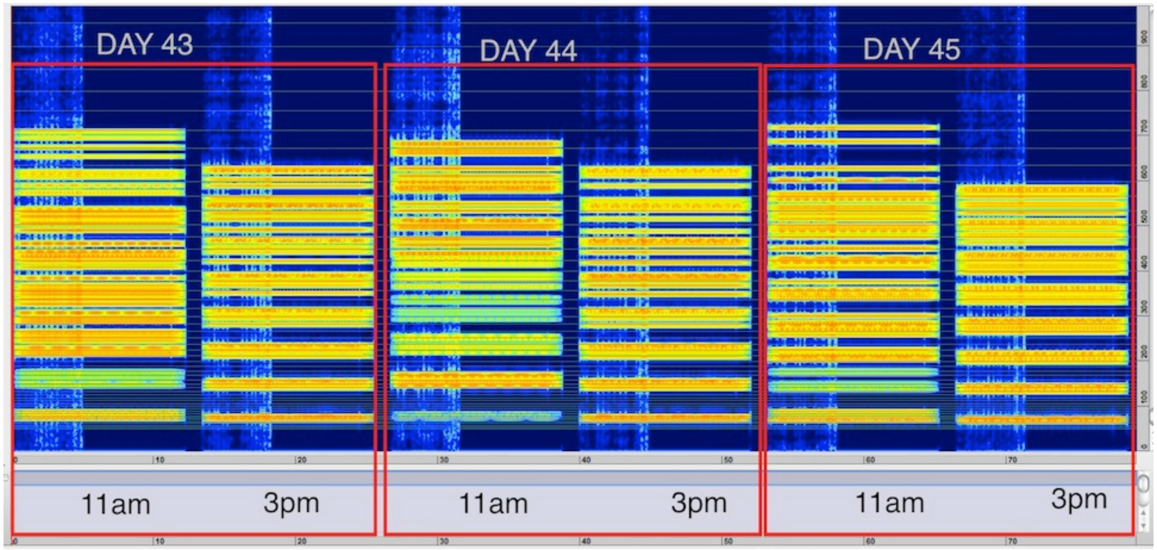


Figure 3.10: Sonogram of Zones 1-8 temperature zone data logged during days 43-45 of the outdoor study. Frequency range depicted spans from 0 to over 700 Hz**.** The grey colored areas inside the individual white horizontal bands of the sonograms illustrate acoustic beating, indicating wave interference.

description of the results of the 45-day study can be found in the scientific article, “Sonification as Art: Developing Praxis for Audifying Compost”.[§§§]

Pedagogically speaking, keeping the temperatures and frequencies tightly aligned in a direct way can help visitor/listeners understand experiencing sonic frequencies as/in Hertz. For example, while each of us is constantly enveloped by sound throughout our day-to-day lives, many people probably do not have the opportunity to imagine our sonic environment as possessing many distinct frequencies. The purpose of mapping the biota’s temperature profile linearly onto audio frequency in the audification, however, is not expressly meant to enable a listener to accurately name the temperature/frequency emitted from a single sensor.

[§§§] Parker, Jennifer no.e. “Sonification as Art: Developing Praxis for Audifying Compost”. In *Proceedings of the 21st International Conference on Auditory Display (ICAD 2015)*. Eds. Vogt, K., Andreopoulou, A., and Goudarzi, V. Graz (KUG), Austria (2015): Institute of Electronic Music and Acoustics (IEM), University of Music and Performing Arts. 157-164.

Aesthetic Justification of a Frequency-Based Parameter Mapping

On the human scale, the spectrum of temperature ranges elicited from the biota during the outdoor research period spanned between slightly cold (50°F) and those dangerous to human health (~110-120°F). Contrastingly, when this data was directly translated to frequency, the resulting signals fell into the mid-low frequency range of human hearing—a sound spectrum that is quite harmless to humans and can be roughly compared to the range of between $A\flat_1/A_1$ in the second octave of a piano. For example, an ambient room temperature value of 70°F translated into Hertz is only a few microtones above the piano's $D\flat_2$ (69.3 Hz) wbhile the higher end of the projected compost temperatures end a few microtones below B_2 (123.5 Hz).

Obviously, a direct, linear mapping of temperature to frequency as utilized here does not immediately correlate with the human experience of the two distinct phenomena of temperatures and sonic frequencies found in this range. However, I have decided to maintain this direct relationship between the two from the conceptual standpoint that use of low frequency sounds aligns with ideas on the human scale that: (a) composting is a relatively slow process, aligning with the slow movement of low frequency soundwaves; and (b) the audification is measuring the biota's terranean-based process of soil creation—an activity that is normally silent and takes place underneath our feet—whereas high frequency sounds are produced by birds and larger organisms that fly above the ground and our heads.

Thirdly, as the resulting audification capitalizes on the existence of closely related temperature readings manifested as acoustic beating, the resulting frequency-based soundscape is much more than the sum of its sonic partials. Thus, the sonification aligns quite poetically with the compost. Here, the millions of seemingly spontaneously generated microorganisms contained in the biota are in the process of transforming food waste into a nutrient rich, soil superfood—also a phenomenon that is also much greater than the sum of its original parts.

SITE TWO: A PUBLIC INDOOR COMPOST TEMPERATURE STUDY

Building a Sonification Research Lab for an Extended Compost Study

A second compost study was built and displayed publicly at the UCR *Sweeney Art Gallery* between June 27 and October 17, 2015—a total of 113-days. Situating compost inside the gallery afforded me the opportunity to design an eight-point audio display for the project. The open BioArt laboratory approach also allowed guests a direct window into my methodologies for the real-time audification and collection of temperature data emitted by the biota.

During the exhibition, temperature variations within the self-organizing mass were continually audified for a period of 53 days—rendering a non-stop, biota- driven "performance" in which the usually silent process of decomposition was made tangible on a human scale. In addition to generating a continual soundscape, temperature data from the live audification was collected every minute and saved as a text file every hour for a period of 30 days. Afterwards, the live compost was removed from the site, and the collated dataset was played back as a time series sonification for the remaining two months of the exhibition.

Background: General Layout and Design of the Exhibition

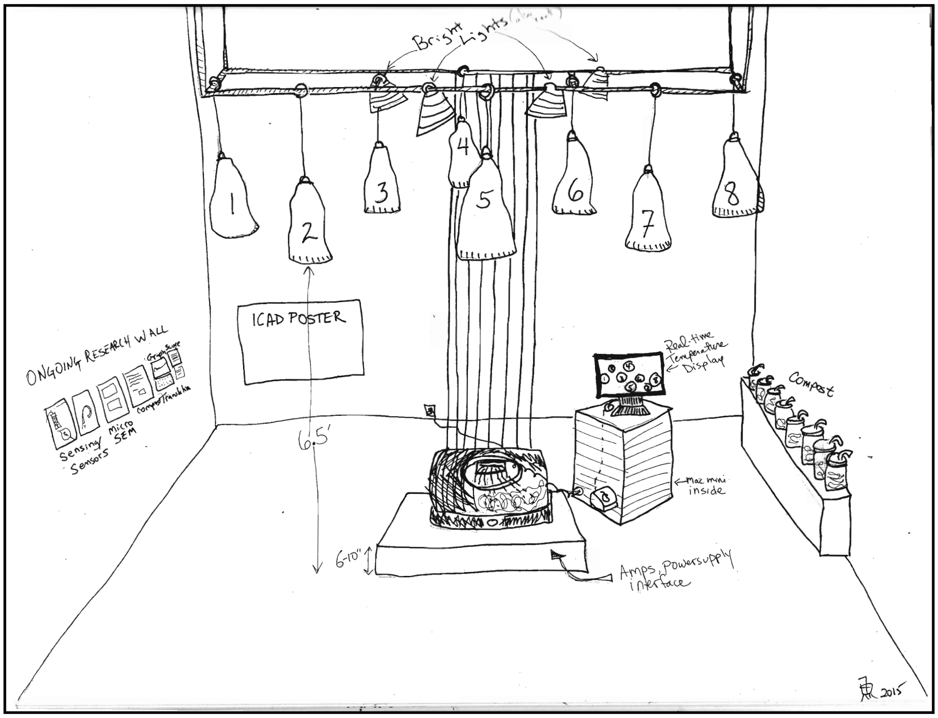


Figure 3.11: Composer's sketch of the BioArt installation layout. Objects numbered 1-8 represent the speakers of the compost temperature audio display.

Figure 3.11 is a design sketch of the BioArt installation layout and shows the compost temperature audio display at the center of the image. The setup included: seven live compost samples, an 8-point auditory display, an ongoing research wall, and an LCD screen visualizing the readings from the compost temperature sensors. Figure 3.12 shows a gallery view of the setup at the *UCR Sweeney Gallery*.

In addition to hearing the silent process of decomposition, gallery visitors were also given a direct window into my methodologies for creating sound of out of data via the data sonification research wall (Figure 3.13). This area of the lab was constantly updated with information on: maintaining an indoor composting environment;

Figure 3.12: *Composing [De]Composition* at the UCR *Sweeney Art Gallery.*

the prototyping of compostable sensors; biochemical fact sheets/soil improvement information for home composters; various information on parameter mapping for the audification and subsequent sonifications; and a scientific poster based on an early version of this paper presented at the *2015 International Conference of Auditory Display* in Graz, Austria.

a.  b. 

Figure 3.13: An ongoing research wall displayed the development of compostable paper sensors (a. rows 1,2), information on composting (a. rows 3,4), data parameter mapping strategies (a. rows 5,6), and also (b) a scientific poster.

a. b.

Figure 3.14: (a) Gallery view: *Eight Jars*—decomposing vegetal matter organized by date (shown in the foreground). Gallery visitors view the stop-frame compost animation titled, *Micro/Macro* (2015); (b) frame from *Micro/Macro*.

The research lab also included two visualizations of the composting process, and a separate interactive visitor station sonifying temperature changes recorded in the 45-day outdoor study. Figure 3.14 shows the compost visualization titled, *Eight Jars* and a still from the five-minute stop-frame video titled, *MicroMacro*. *Eight Jars* consisted of eight half-gallon jars of my decaying food scraps labeled according to the date each container was placed inside the gallery. *MicroMacro*—taking its inspiration from Charles and Ray Eames' film, *The Powers of Ten* (1977)—juxtaposes different levels of reality that exist in compost. Shot between January and May 2015, the macro reality is illustrated with 1000 close-up digital images of my kitchen vegetable waste emptied into a series of composting containers located outside of my home. The micro viewpoint of the biota was achieved through the integration of scanning electron microscope images of the compost taken at different magnification zoom levels ranging from 100–10,000x. This gave viewers varied microscopic viewpoints of the biota's terrain and the tiny inhabitants that generated the heat/sound for the installation.

The final aspect of the sonification lab was an interactive sonification station (Figure 3.15). Here, visitors could explore sonifications created with data from the initial 45-day study. Using the provided LCD display, headphones and mouse, participants navigated the dataset to hear differences between daily temperatures.

A second window in the interactive area featured a navigatible, screen-based replica of the biota with different temperature zones represented as numbered fields. Here, guests could traverse a virtual biota while hearing temperature differences between areas by dragging the mouse through each of the numbered fields.[****] Figure 3.16 below shows the user interface for the MAX for the interactive data sonification station.

a. 

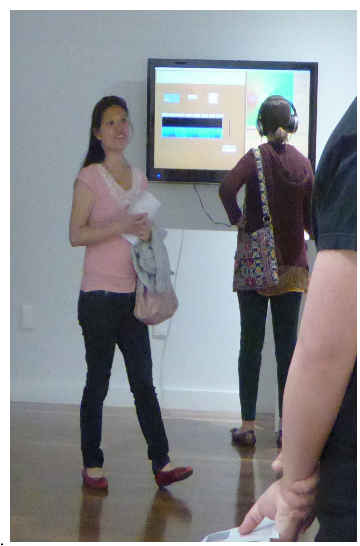
b. 

Figure 3.15: Interactive sonification station. Visitors navigated temperature data from the 45-day study.

[****] Based on the CNMAT RBFI object by John MacCallum ©2010, UC Regents.

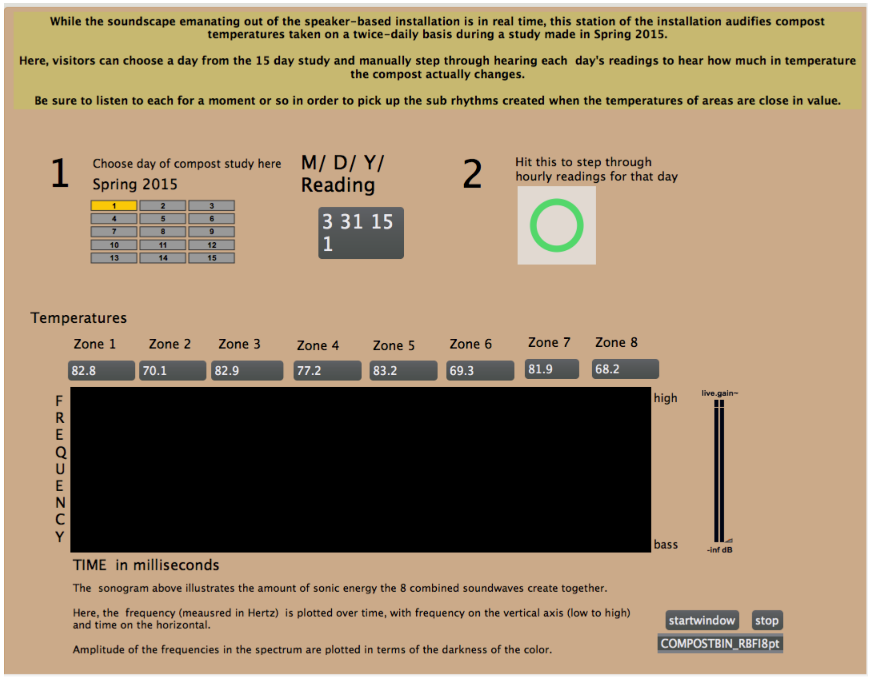
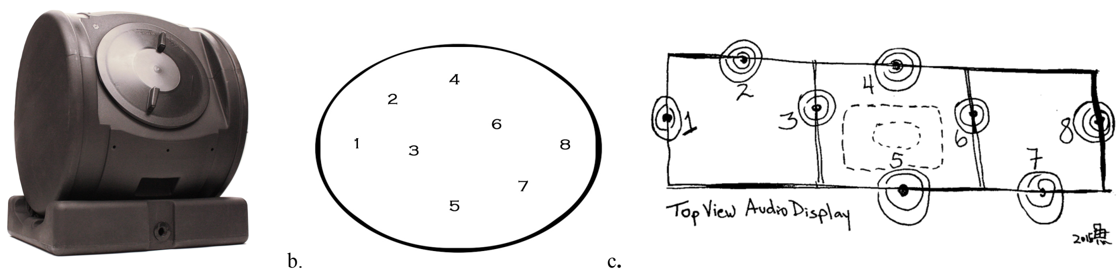


Figure 3.16: User interface for the 45-day compost data sonification Listeners could scroll through different days of the study to hear temperature changes over time. Programmed by J no.e Parker (© J no.e Parker 2015).

Audifying the Biota: Localized, Yet Dynamic

As the design of the sensing device itself and its OSC/MAX/MSP coding has already been discussed above**,** I will restrict my discussion in this section to a description of the basic temperature sensing environment. Live temperature sensing was done on a continual basis for 53 days, while collected data sets were sonified for the final 50 days of the study.

As a data sonification artwork, it was of utmost importance for visitors to the research installation to easily understand the metaphor created between compost and the sonification's audio display—to achieve this end, the compost container was divided into eight "zones"—with each temperature sensor numbered and assigned its own "zone", and mapped directly to one of the eight audio display speakers above the bin. The speakers



a. b. c.

Figure 3.17: (a) The composting container used for the study indoor; (b) the general arrangement of the temperature sensors inside the compost bin; (c) also reflected in the layout of the spatialized audio display.

were also similarly aligned with the placement of the sensors inside the container—thus easily facilitating a direct conceptual connection between the sensors and the speakers for visitors. Figure 3.17 illustrates (a) the study's composting container; (b) the placement of the temperature sensors inside the biota; and (c) a sketch showing the positioning of the audio display as imagined from above. The elliptical arrangement of the sensors was dictated by the compost tumbler's design—positioned on its side rather than in an upright position, giving the compost's surface area an elliptical shape.

After each turning of the compost, sensors were replaced in relatively the same position as before, establishing each area as a specific "temperature zone". In addition, the design of the composting setup inadvertently facilitated temperature readings taken at multiple depths inside the compost. For example, centralized temperature zones four and five of the bin were more shallow and less insulated from the outside room temperature than in zones three and six, also centrally located in the biota. Sensors in temperature zones one and eight shared the same depth as centrally located three and six, however, being situated near the ends of the container, they were less insulated from the outside room temperature.

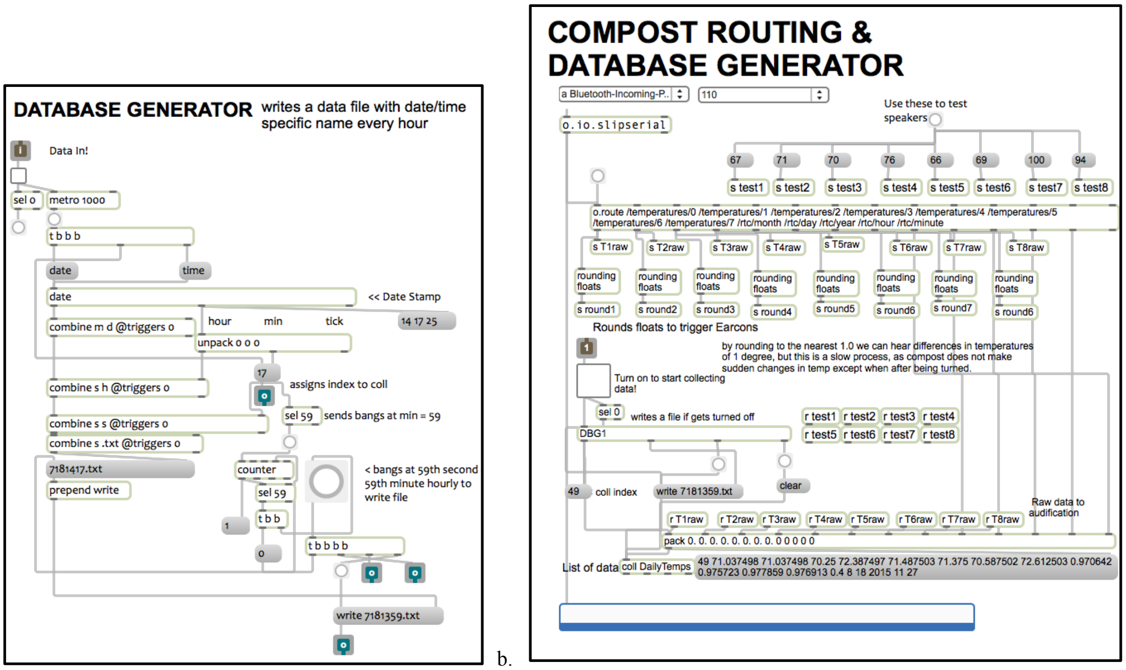
The positioning of the temperature sensors inside the biota was relatively static during the course of the study, however because of the weekly need to add new vegetable matter followed by mixing/tumbling/aeration, the biota itself was not static. Each time the compost was "fed" and aerated, the eight thermocouplers were removed and replaced in roughly the same area of the compost bin. Although it was highly unlikely that material from the left side of the bin migrated over to the right side due to the design of the tumbler, the microbes/decaying material monitored by the area's temperature sensor were definitely not the same after turning. Therefore, the concept of monitoring localized changes within the pile is actually a construct that refers to the relationship between the sensors and the individual speakers of the audio display, rather than to the biota.

CODING FOR THE 30-DAY TEMPERATURE STUDY

As mentioned above, the biota was audified 24 hours a day *in situ* for a period of 53 days. The live compost was removed from the gallery on day 53 and the collected data set was then sonified by the audio display on a continual basis beteween days 54-113. The research/exhibition period concluded with a public Data Listening Session where the data set was translated into MIDI note number with microtonal gradients and presented as a spatialized work for electronic piano.

Data Sonification and Management

The object *DBGenerator* (Figure 3.18(b))*,* is a MAX/MSP patch that was designed to collect, collate, and save the array-based data as text files. *DBGenerator* captured and time/date tagged temperature data from the eight-sensor array once every minute. After



a. b.

Figure 3.18: (a) Subpatch *DBG1* that collates and saves a date stamped text file every hour of the study; (b) DBG1 situated inside the *counpost_routing_db* main patch dealing with temperature sensing data.

an hour, the object saved the coll as a text file named by the day/month/hour it was created. 24 files were generated per day, each containing 60, eight-component lists of temperatature data. The total amount of data collected resulted in 1,440 lines of information per day per temperature sensor.

DBGenerator is integrated as a sub-patch inside *compost_routing_db*—a somewhat expanded version of the main compost temperature routing patcher, *CompostRouting* explained above. *Compost_routing_db* is shown in Figure 3.18 (b). *Compost_routing_db* was then integrated into the top-level compost audification patch *AudificationStation* (Figure 3.19). It is in this main patcher where each temperature sensor’s data is directly translated into Hertz.

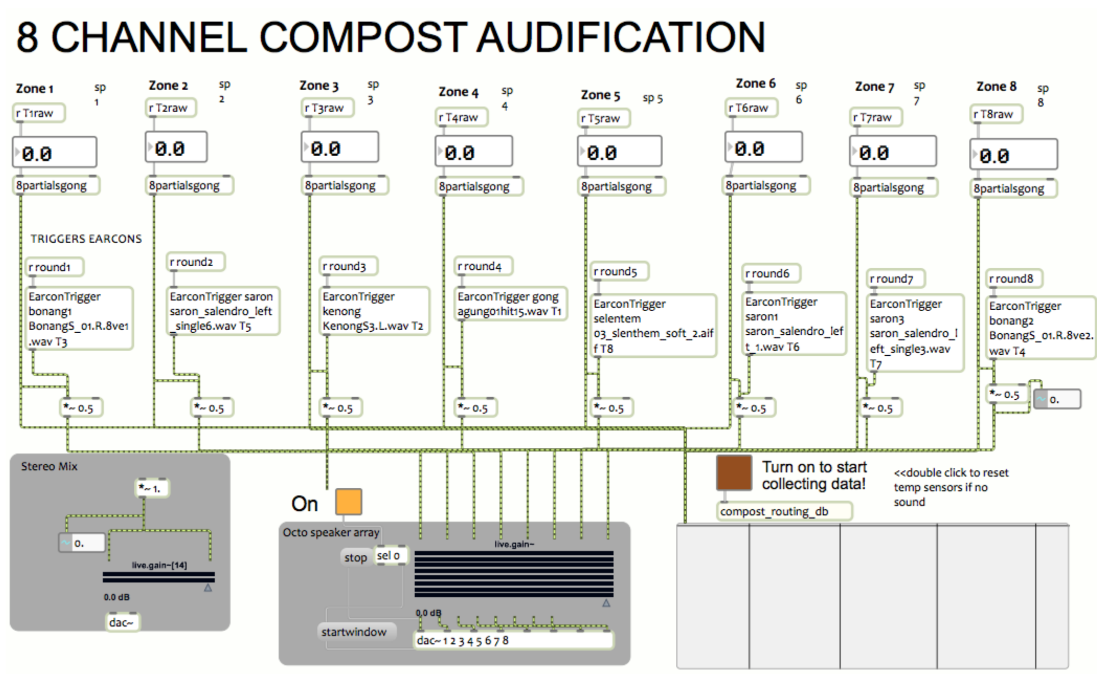


Figure 3.19: Detail of the top-level patcher *AudificationStation* used for the compost temperature data sonification.

During the initial outdoor study the temperature sensors themselves determined the partials of the resulting Hertz-based soundscape, briefly discussed above. This initial approach was changed for the gallery-based stage of the project, however. Instead of

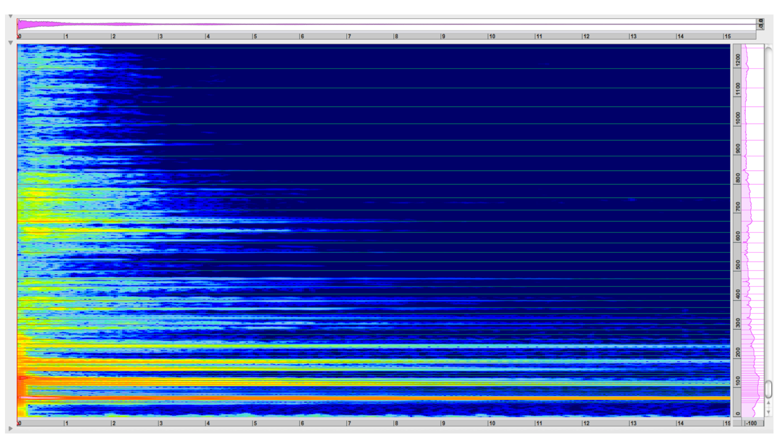


Figure 3.20: Sonogram of a Javanese gong recorded at *Indonesian Conservatory of Arts* (*ISI*) in Yogyakarta, Java was used to determine the partials of C{D}C's Hertz-based audification (Note: Individual waveform shown in pink at the top of each sonogram).

using wavetable synthesis, I synthesized a gong sound to emulate a sonogram analysis of a Javanese *gong agung* I recorded at the *Indonesian Conservatory of Arts* in Yogyakarta, Java (Figure 3.20). The choice to use this new sound was based on my integration of gamlean-based earcons (discussed below) to signal gradual changes in the biota's temperatures.

My discussion now returns to the top-level patcher *AudificationStation* shown in Figure 3.19 above. Using temperature data sent by the object *compost_routing_db*, *AudificationStation* sets each datapoint as the fundamental frequency of one of eight distinct synthesized gong tones created the object *8partialsgong.* Figure 3.21 details *8partialsgong*—an additive synthesizer that employs each sensor's data to 'detune' its own discrete gong tone emulating the gong sound shown in Figure 3.20.

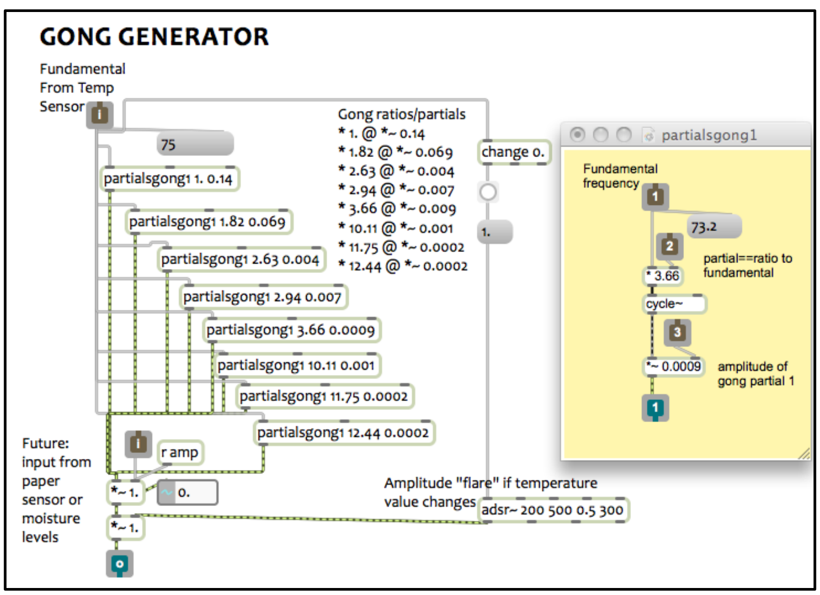


Figure 3.21: The subpatcher *8partialsgong/GongGenerator*. Inset: detail of the subpatcher, *partialsgong1*. *8partialsgong* processes the raw temperature data through 8 iterations of *partialsgong1.* Ratio and amplitude information for each partial is listed in the provided "gong ratio/partials" list.

Each temperature-tuned gong sound then is amplified by a correlating speaker in the audio display.

Earcons: Hearing the Rate of Temperature Change

Partialsgong1 was also programmed to dynamically accent a data point with a short (500 millisecond) burst of amplitude when it detected a total change of one degree in value from any sensor. However, this was done in an effort to create a dynamically morphing soundscape, rather than to help visitors to the lab determine which area of the biota was heating up or cooling down. To better enable listeners to locate *which* of the temperature sensors were changing at any given time, a third object titled, *EarconTrigger* (Figure 3.22) was also included in the main *AudificationStation* patcher (Figure 3.19). *EarconTrigger* functions as an alarm alerting visitors when an area in the biota's temperature has changed by $\pm 1^{\circ}$F with one of eight, distinct *salendro*-tuned gamelan earcons.

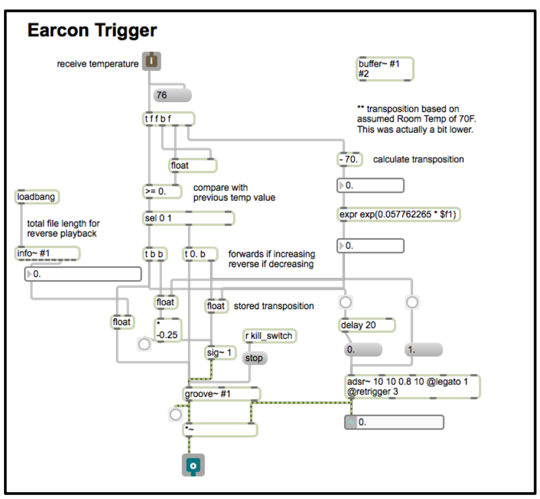


Figure 3.22: The MAX object *EarconTrigger* evaluates incoming data and triggers a directional, sensor-specific gamelan earcon when a change of one degree in temperature is detected.

According to McGookin, “one-element earcons are the simplest type and can be used to communicate a single parameter of information. They may be only a single pitch or have rhythmic qualities”. [10] The earcons acted to inform visitors not only when but *how* the localized temperature sensors detected an aggregated change by sounding a directional (forward or reverse), gamelan instrument sound. The inclusion of the gamelan earcons not only served to alert listeners to temperature changes in specific areas, but they also very clearly revealed the nature of temperature change within the slowly evolving biota.

Observing the biota for an extended period of time in the indoor space not only confirmed how the nature of its temperature change was in no way instantaneous—but surprisingly, also how it was rather a gradual, almost rhythmic process. Since the biota was situated indoors, changes of one degree could intermittently stretch out over a matter of hours—without the help of the sun’s thermal energy or outside air temperature. As the one-degree of change threshold was reached and then relinquished again, the earcon would sound intermittently forward-and-reverse sometimes for very extended periods of time. A listener lucky enough to be present at these times could witness the slow and tenuous process from anywhere between less than one minute to up to 60 minutes.

Soundscape

Walker and Nees have established that

> soundscapes—ongoing ambient sonifications—have been employed to promote awareness of dynamic situations. Although the soundscape may not require a

> particular response at any given time, it provides ongoing information about a situation to the listener. [11]

As such, visitors to the gallery heard what happened as the biota was left to its own devices, as the soundscape slowly, even sometimes imperceptibly changed over time.

The resulting installation was designed to enable visitors to experience sound and data in an analytically interesting manner. Inside the gallery, visitors were immersed in an eight-point, spatialized soundscape created by the temperature sensors and controlled by the biota. Positioning of the eight speakers in the gallery to mirror the placement of a corresponding temperature sensor in the composting container not only forged a strong conceptual connection between the biota and the resultant soundscape, but it also allowed visitors to create their own audio "mix" by physically moving around the room underneath the speakers. Although the sound of the Hertz-based mapping of any particular area of the biota was more focused when listeners were positioned directly under a temperature sensor's corresponding speaker in the gallery area, the composite eight-point soundscape was far too complex for the listener to accurately analyze each of distinct temperature data singularly. Instead, the complex soundscape sonically and aesthetically represented the real-time temperature state of the *entire* biota—translating it into an eight voiced, spatialized, drone generator.

According to Grond and Hermann, "the tight relation between action and perception is important for… engagement with the sound: [if] the sound is clearly anchored to a physical cause… this closed loop allows us to correctly interpret the information carried by the impulse response in relation to impact". [12] For example, if the temperature in one area of the biota was higher or lower than in another, the frequency of the sound emanating from the speaker related to that specific zone reflects that difference, sounding higher/lower. Moreover, the spatialization of the resulting soundscape situated around the gallery space invited visitors to imagine themselves moving around, inside and between the different zones of the compost container.

Unfortunately, it proved virtually impossible to accurately record the actual 8-point soundscape experienced over the course of the study. However, sonogram analysis of monaural mixes of the data can still serve as a tool in revealing the soundscape's dynamic nature. Figure 3.23 below shows the sonogram analysis of datapoint 13192 taken from Zone 1 of the biota (forthwith called Z1/13192). This datapoint was collected at the beginning of day nine of the gallery-based study. Here, the value of the datapoint (73.3) is directly translated as a the fundamental frequency of the gong sound created by the *8partialsgong* synthesis engine. The datapoint(s) in Figure 3.23's examples below were looped for 3-5 seconds in order to more easily analyze them.

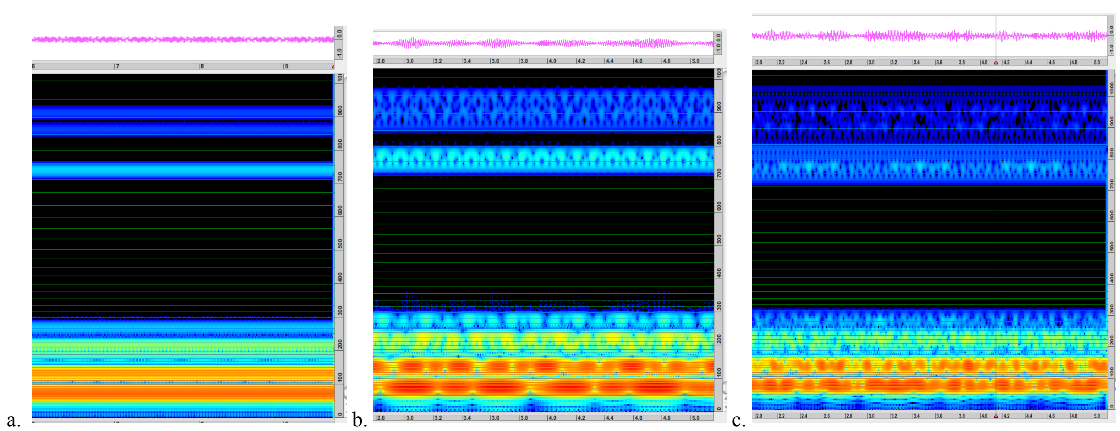


Figure 3.23: Sonogram analysis of a 3-second loop of (a) data point Z1/13192; (b) simultaneously sonified datapoint 13192 in Zones 1-4; (c) simultaneously sonified datapoint 13192 Zones 1-8. Notice the increasingly complex patterns and expansion—especially noticable in the upper overtones—caused by acousting beating. (Note:Individual waveform shown in pink at the top of each sonogram).

Returning to 3.23(a), the darkest red/orange bands of the sonogram fall below 100 Hz and show as strongest in the sonic profile—as would be expected as the fundamental is 73.3 Hz. Other lighter-colored materials occuring higher in the sample's frequency range show overtones in decreasing amounts. The continual looping/sounding of the data point during the sonification strengthens these overtones and appears as bands of color in the sonogram. Overtones are seen in the strong aqua and light blue bands in the 700-950Hz frequency ranges in Figure 3.23(a).

After analyzing the sonogram of a single datapoint, my disuccsion now turns toward an analysis of what happens when simultaneously sonifying multiple data points. In an attempt to give the reader a view into the complexity of the compost's temperature-generated soundscape without actually being able to hear it, I will re-construct a single moment from the collected dataset using MAX and use sonogram analysis to suggest/simulate a visualization of the sonic results. To accomplish this, I have created two different sonogram-based sonification "mixes" below—using datapoint 13192 found in Zones 1-4 for "mix" one, and sonifying the same datapoint found in Zones 1-8 for "mix" two. Again, both these mixes are NOT meant to be representations of the resultant soundscape of the gallery, as acoustical space has not been considered at all in this simulation. Rather, I construct these visualizations to enable the reader to analyze the complexity of the sound environment created by the biota and to illustrate the constant acoustic beating that occurred.

Figure 3.23(b) shows sonified data point 13192 for Zones 1-4 while Figure 3.23(c) shows the sonogram for Zones 1-8 combined. After comparing these two sonograms, notice in how both the spectrum and the visual texture in the area of the overtones is more filled out and complex as more channels are added to the mix—this is the result of the waveform convolution that occurs acoustic during acoustic beating.

Next, I will round out this conceptual disucssion of the “unrecordable” soundscape experience using the same visualization strategy as above. While the sonograms in Figure 3.23 above illustrate what happens when more temperature data is added to the soundscape for a single datapoint, Figure 3.24 provides a songrams of eight sonified data points across time. Using this information, we can analyze a basic trajectory of temperature changes that occurred across all eight zones between days 7-10 of the study.

Table 3.2 illustrates all recorded compost temperatures for each data point in Zones 1-8. Visual analysis of the sonograms across datapoints 10500 (collected right after aeration on day 7), 11752 (collected on day 8), 13192 (collected on day 9), and

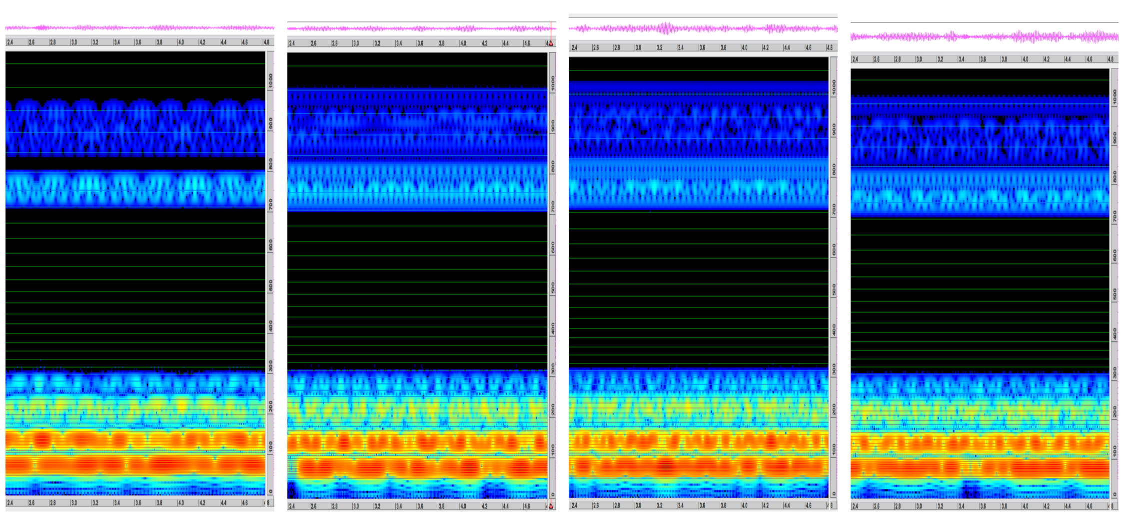


Figure 3.24: Sonogram analyisis of 8-zone sonification of datapoints 10500, 11752, 13192, and 14500 respectively. Although pattern differentiation between different datapoints—representing the overtones and convolution produced by the acoustic beating—is evident across the entire frequency spectrum, differences are most easlity visible in the 800-1000 Hertz frequency range (See Appendix for large scale sonograms).

14500 (collected on day 10) illustrates how the gallery sounscape subtly morphed over time. Moreover, it reinforces my aesthetic justification for deploying a direct, Hertz-based parameter mapping—the sonograms show definite changes occurring within the soundscape are indeed in metaphorical alignment with the slow, physical changes occurring within the biota.

Table 3.2

Compost Zone Temperatures Across Datapoints between Days 7-10 of the Sweeney Gallery Study

Day	*Data point*	*Zone 1*	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*Zone 6*	*Zone 7*	*Zone 8*
7	10500	73.2	76.1	76.9	75.1	82.4	77.4	77.0	79.9
8	11752	72.4	74.5	76.0	74.5	80.5	76.6	75.9	79.0
9	13192	73.3	76.1	76.9	75.1	82.4	77.4	77.0	79.9
10	14500	73.6	75.3	76.6	74.9	81.4	77.0	76.3	79.7

These sonograms prove—much like the biota itself—that this approach toward data audification revealed much more than its own basic ingredients. The acoustic beating that occured between closely related temperatures created a thick, viscerally subrhythmic texture, multiplying the interiors of the eight waves in a way that can directly refer to the uncountable organisms that were busily at work inside the compost. Aesthetically speaking, the resulting soundscape can be described to have a very subterranean and insect-like quality, due to the nature of the complex, constant, yet arhythmically beating, low frequencies. In fact, I have experienced naturally occurring insect soundscapes similar in texture to this audification (but not frequency range) during the predawn hours on the tropical island of Bali, Indonesia.

A DATA LISTENING SESSION: *Publicly Presenting the Results*

Figure 3.25 plots the biota's entire temperature profile measured over the 30-day data collection period. Each colored line represents one of the eight temperature sensors placed inside the biota. Graph resoulution is measured at 1,400 points/day, with a temperature reading recorded every minute. 43,400 data points were collected for each temperature zone, with the entire dataset totalling 347,200.

Scattered temperatures at the beginning of day one reflect the biota's adjustment from being moved from an outdoor composting container to the bin situated inside the gallery. Large decreases in the temperature plots at days 7, 10, 17 and 23 indicate days when the temperature sensors were removed to and new organic material was mixed into the pile. These low temperatures do not reflect actual compost temperature, but rather the gallery's ambient room temperatures when the sensors were removed to turn and "feed" the biota.Subsequent quickly increasing temperatures reflect sensor replacement into the biota.

The severe temperature increase at day 29 resulted from the biota bieng moved outdoors for two hours, on a day that the outside air temperature was recorded at 93˚F. It is interesting to note that after only two hours of outdoor exposure, the biota reached nearly that same temperature. Greatest temperature variation over 24 hours occurred at day 10 with a 9-11˚F difference between all areas. The highest temperature at this time was recorded in Zone 8 (81˚F) —an outermost region of the pile—while the lowest

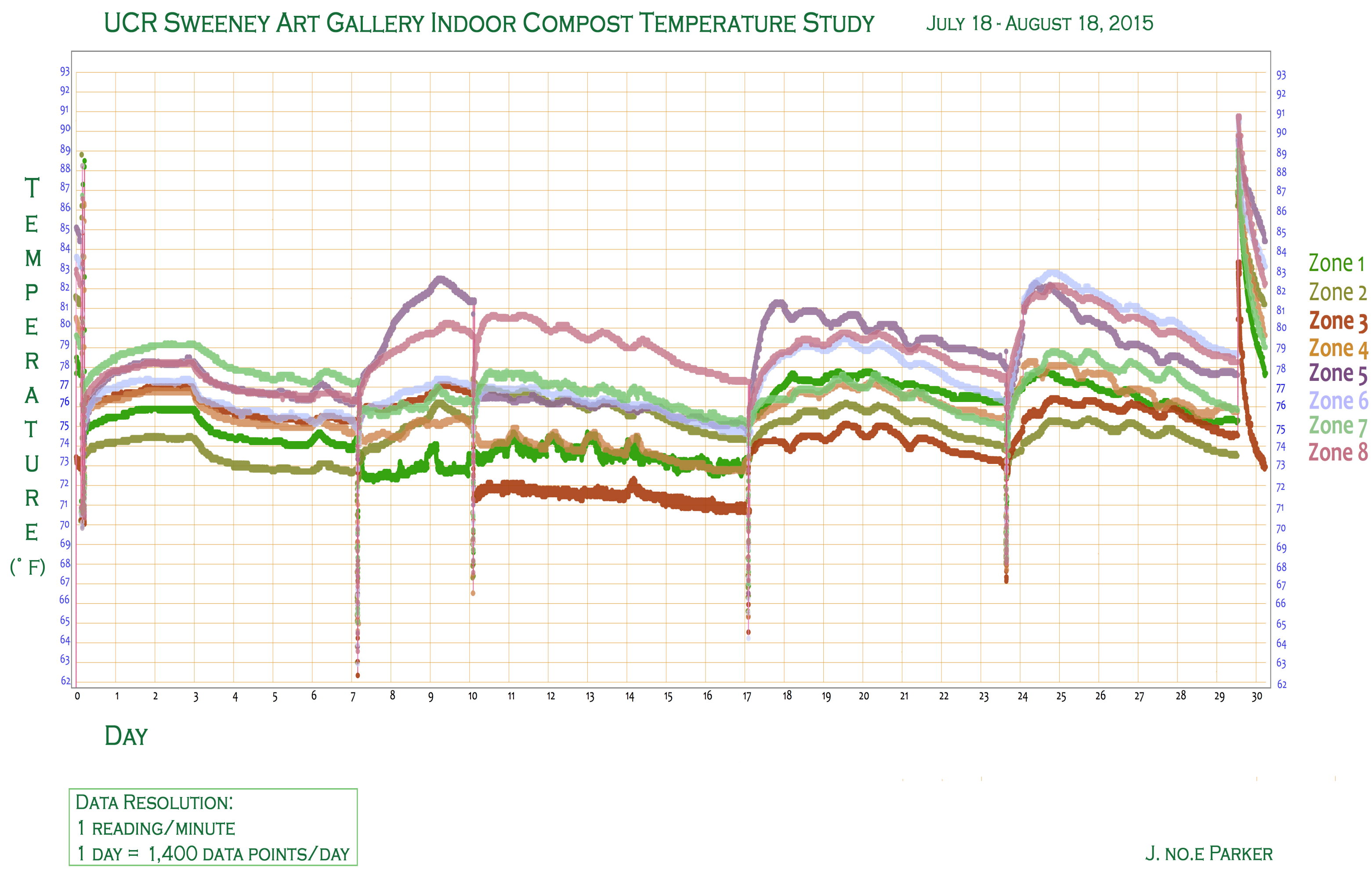


Figure 3.25: Results of the 30-day indoor compost temperature study.

temperature (71˚F) was found in Zone 3 near the container's center—results that were somewhat surprising.

From Audification to Sonification

On day 53 of the installation, the live compost was removed from the gallery and a data playback engine replaced it. The earcons were deactivated[††††] and different playback rates for the data were experimented with in order to determine the best data read-rate-to-sound quality. I primarily based my judgement criteria for this on the overall "feel" of the speed of the soundscape, however, I was also driven by the desire for gallery visitors to experience an entire reading of the data within one visit. Once all this was figured out, the MAX/MSP program sonified the standalone datasets for the final half of the exhibition.

While the original, real-time duration of the audification lasted 30 days, the playback rate used for the listening session was compressed to 1 line of data per 45 milliseconds. This number was derived from listening to the dataset played back at rates of 1 /1000 ms, 1/100 ms, 1/45 ms, and 1/10 ms. At a playback rate of 45 ms per file, the experience of listening to the nearly 350,000-member dataset was condensed down to a total of 30 minutes. Data playback rates faster than 45 ms did not allow the data to be heard as individual points—greatly muddying the results, with sonic differences extremely difficult to discern. Figure 3.26 below shows *SonificationStation*—the MAX patcher I developed to read and sonify the datasets.

[††††] The earcons were deactivated due to the high-speed reading of the dataset.

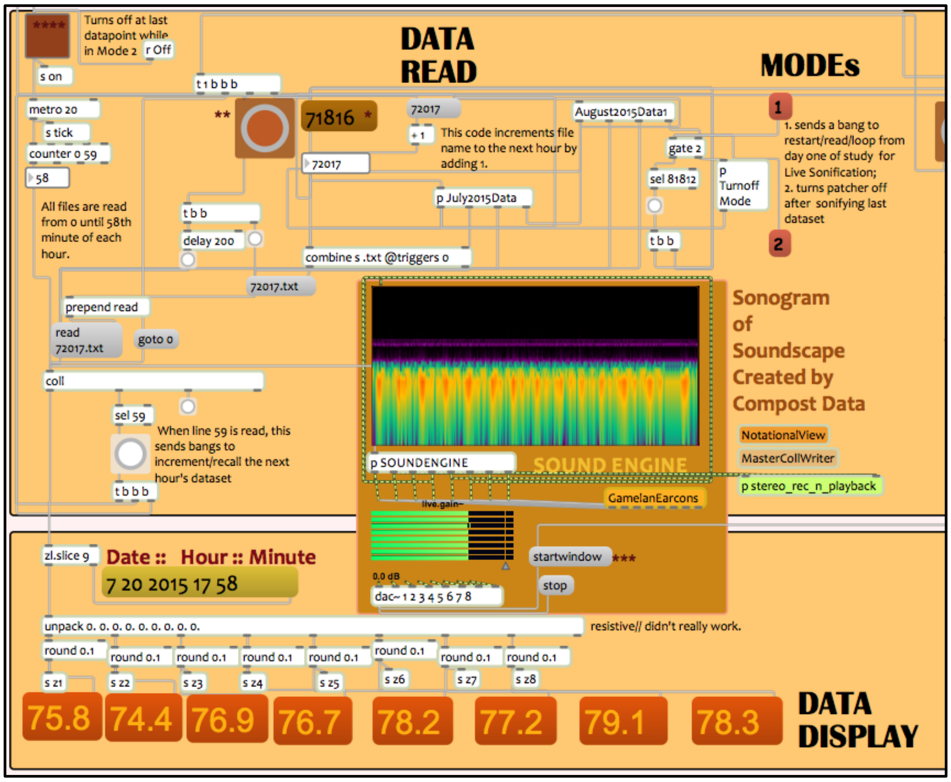


Figure 3.26: Patching view of *SonificationStation*, the data-reading engine developed for sonifying the compost temperature dataset. (© J no.e Parker 2015).

A MIDI Note Number Data Sonification

The hour-long Data Listening Session was publicly presented at the closing of the gallery-based study. At the event, the dataset was sonified in two ways.

Upon entering the gallery the audience of UCR faculty, students and members of the general public were asked to grab a yoga mat and position themselves underneath the eight speakers of the audio display to hear a short talk given by me on the project while the original, Hertz-based data audification played in the background (Figure 3.27).

After my talk concluded, I asked guests to turn off all their portable devices and lay down face-up on the floor on their mats to hear a MIDI-based microtonal sonification

a.  b 

Figure 3.27: Visitors at the 8-point spatialized compost temperature "Data Listening Session" (a) heard a gallery talk given by me explaining the project before (b) settling in for the MIDI note number rendition of the dataset.

of the data realized by eight virtual electronic pianos. Guests who remained seated around the outer perimeter of the audio display could watch a magnified projection of live compost microbes—affording a window into the microscopic world responsible for the creation of the work. Technically speaking, the setup for the MIDI based sonification was somewhat different than that for the Hertz-based version. Although all data processing was executed inside the MAX programming environment, the resulting sound was generated in the *Ableton Live* DAW environment. The MAX patcher *MIDINote#Master* shown below in Figure 3.28 (a) performed simultaneous reading of the biota's eight temperature zone datasets, MIDI note number mapping, and conversion of each datapoint's fractional portion into unique pitch-bend information. *ZonePitchBender* (Figure 3.28 (b)), a subpatch located inside of *MIDINote#Master* was programmed to convert the abovementioned fractional aspect of each datapoint into pitch-bend information. Finally, all MIDI information was then sent out of MAX into its own audio channel within the *Ableton Live* mixing environment (Figure 3.28).

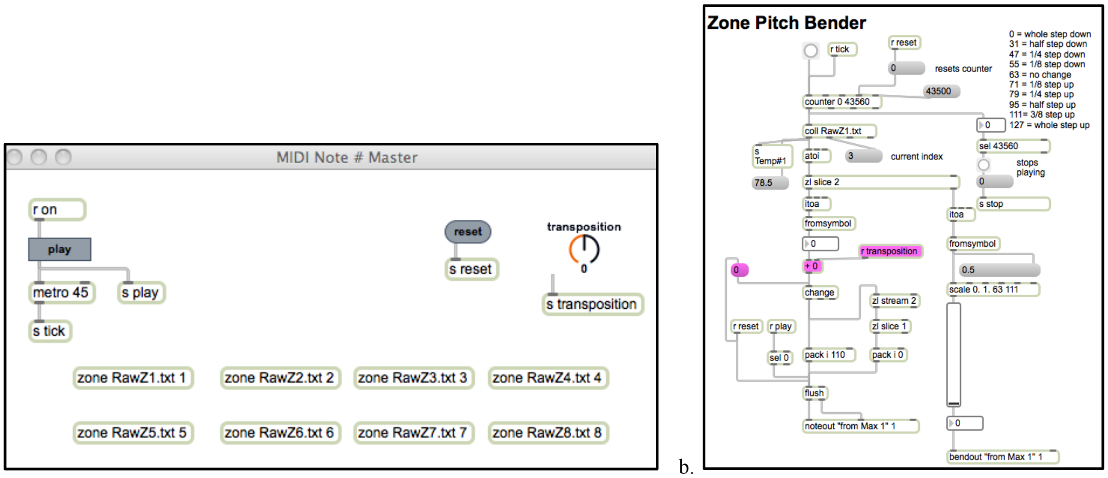


Figure 3.28: Eight unique iterations of the object *ZonePitchBender* object (b) contained in the *MIDINote#Master* patcher (a) send floating-point MIDI note numbers into corresponding audio channels in *Ableton Live*.

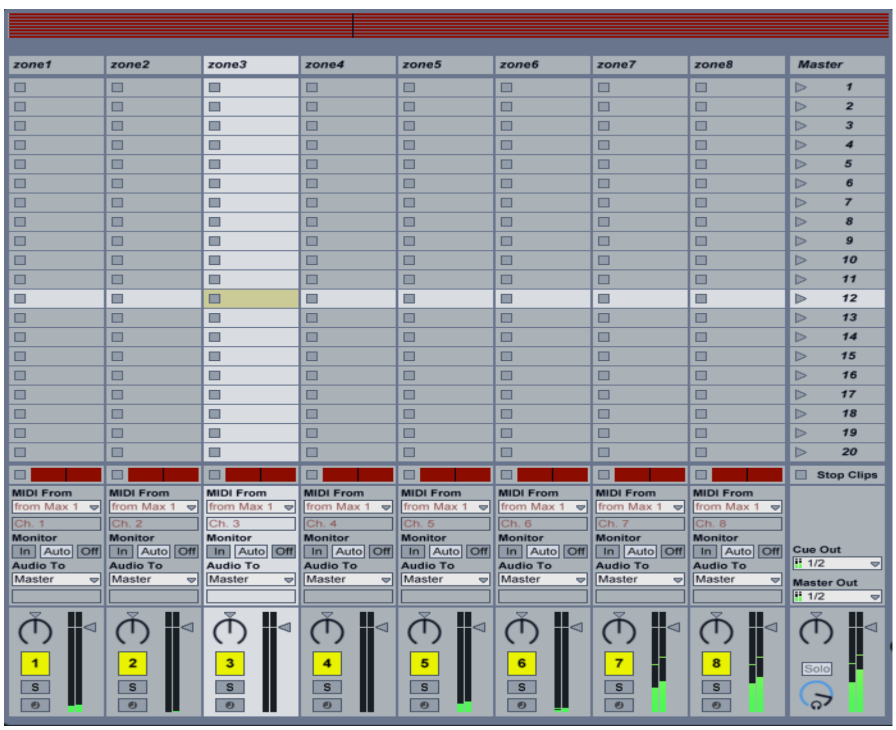


Figure 3.29: *Ableton Live* mixing environment. MAX MIDI data for each temperature zone is accepted into a separate channel inside the *Ableton Live* mixing environment and is voiced as one of eight identical microtonal pianos.

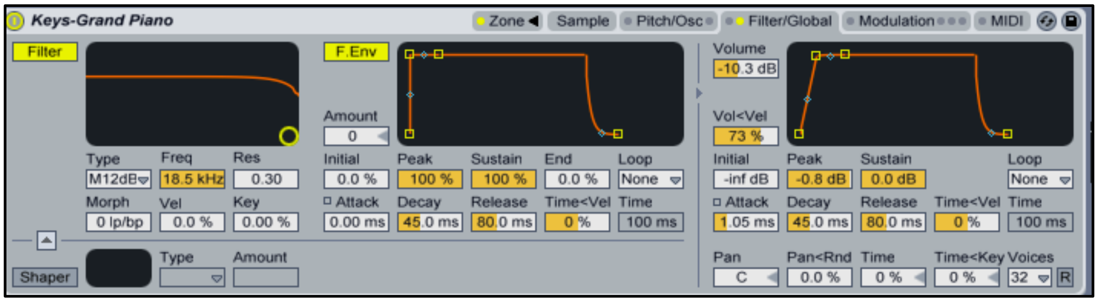


Figure 3.30: Eight iterations of this *Ableton Live* Grand Piano instrument was used to voice the eight datasets of the microtonal sonification.

Timbre

My intention for the MIDI note number based sonification was to enable listeners without any previous musical knowledge the ability to quickly and directly analyze discrete, localized changes between temperature zones. At first, I considered representing each temperature zone as a different timbre, as the approach seemed to make sense intuitively, however in reality it obscured my ability to analyze changes *across* the dataset and resulting spatialized sound field. After testing this idea in *Ableton Live,* I noticed that minute changes between different zones were overshadowed if there were different timbres sounding simultaneously. Using different instrumentation for each zone—although making the sonification more texturally complex—completely erased any ability to focus the ear on detecting discrete changes between temperature zones.

As a result, the timbre of an eight-voiced microtonal grand piano was chosen to sonify the biota. Figure 3.30 shows a detailed view of the envelope filter used for the pianos. The final choice to use the sound of a dry, Western piano rather than an electronic instrument or waveform generator was made to contrast with the complex, Hertz-based sonification.

According to Emmerson, the use of easily identifiable instrumentation minimizes the 'search engine' aspect of the listener's perception system [13] and allows the changes heard take a front seat. The sound of a piano has become sufficiently ubiquitous to many listeners, even worldwide—given our current globalized, internet-centric age. Therefore, my use of a microtonal piano here creates a familiar, but still somehow unfamiliar texture for the audience—inviting close and focused listening. The use of the spatialized audio display for data playback afforded listeners the opportunity to directly compare the changes in temperature as microtonal variations as well as observe where they happened in the biota—transmitting the biota's localized temperature changes to corresponding points in the room.

CONCLUSIONS*: On Mapping and Listening to Data*

Data sonification and listening to it are relatively new areas for both researchers and general audiences. It is a new way of listening—not only for enjoyment or entertainment, but also as a way toward opening the mind and body to new sensory experiences of all types of non-audible phenomena. Data visualization and sonification have successfully been applied to better apprehend both naturally occurring and synthetic systems—such as temperature in compost samples (in the case of *C[D]C*), stock market trends, Iraqi war body counts, weather patterns, etc.

While data visualization allows the viewer direct visual and mental access to understand relationships between various types of information through time or as ratios, this apprehension remains firmly rooted in a somewhat cerebral and superficial realm. Data sonification on the other hand, allows recipients to experience data sets *viscerally*—

not to be visually scanned in seconds as static points/plots on a pie diagram as in a cross-sectional data representation or graphed as a time series, but rather to be *felt* through the skin and auditory organs as part of a concrete, temporally-based matrix. If the parameter mapping has been transparent and the sonification meaningfully spatialized, listeners can experience the information/phenomenon expressed in the three-dimensional world.

It is not the task for a listener to interpret individual sounds of a sonification per se, but to hear the data collection and *apprehend changes within* it. The 8-point spatialization of the audio display afforded a deep understanding of the biota's complex temperature matrix. The immediate perception of difference/changes between zones was afforded by the direct correlation between temperature sensors and speaker placement around the room.

My choice of a direct, linear to mapping of temperature to microtonal MIDI note number for the Data Reading Session provided a very straightforward and sonically clear way to present the dataset to the audience, as (1) the data remained transparent; and (2) the resulting sonic material remained relatively culturally non-biased. It is my feeling that the decision to use a microtonal electronic piano mapping focused on minute variation effectively transmitted the presence and quality/degree of close changes within the biota. Hopefully, when the exhibition travels to diverse venues across the world, the dataset can be apprehended without allusion to other types of sono-musical expression.

The choice of a MIDI note number parameter mapping for the realization of this sonification also brought up the question for me as to whether or not a musically-based scaling system should be applied to interpreting the dataset. Although major and minor scales have often been used in other data sonification projects, after working so closely with every aspect of the data, I feel that this type of translation does not allow the data itself to take precedence in the resulting work. Rather, it is rounded to conform into a predetermined mold. Moreover, data transformed in this way may not be immediately/directly meaningful to listeners worldwide, as Western tonality also has many overt implications to be of use for strict, analytical purposes. For example, the choice of a minor scale to filter the data might unintentionally arouse specific emotional reactions or even expectations for Western audiences familiar with a classical music tradition firmly in place for 300 years, while listeners in China, Egypt, or Indonesia—areas of the world also possessing rich musical cultures based on distinct, aesthetically-based systems—might associate the sonic material in a different way.

Processing the data through an added layer of musical scaling—especially in the case of this project, after observing such minute changes in the biota's microclimate—would virtually nullify the *actual* relationships between the datapoints. In light of this, I feel that by employing a parameter mapping not connected to any particular, culturally-specific musical tradition—such as a microtonal piano or Hertz—is the most direct path toward connecting listeners to the abstract dataworld. Deployment of both the Hertz-based and microtonal renditions was successful for generating different, data-based listening experiences for the audience. The dense, constantly beating, low frequency range Hertz-based parameter mapping created an acoustically throbbing, somatically immersive sound environment in close metaphoric alignment with the actual physical processes carried out in the biota. On the other hand, the microtonal, pitch-based sonification also allowed listeners to feel as if they were inside the biota, but listening to it in a different way.

Whereas the primary mode of apperception of the data in the continual, Hertz-based soundscape could be described as if entering into a singular, sonic mass, the microtonal version rendered a more cerebral sonic experience. Eric Johns, a listener at the data reading session stated, “I felt like I was in the pile. The [microtonal version of the data sonification] pushed me into a forced state of being, of observation—I began to notice patterns emerg(e)[ing] later on in the reading [session]”. [14]

Notes

1) Jane Bennett. *Vibrant Matter: A Political Ecology of Things* (Durham: Duke University Press, 2011), viii.
2) David Crohn, “Composting and Solid Waste Management” (Environmental Sciences Lecture, University of California Riverside, Riverside, CA, February 12, 2012).
3) Nancy Trautmann, Tom Richard, and Marianne Krasny, “The Science and Engineering of Composting,” Cornell Waste Management Institute, Department of Crop and Soil Sciences, http://compost.css.cornell.edu/monitor/monitortemp.html (accessed May 17, 2015).
4) George Lakoff and Mark Johnson. *Metaphors We Live By* (University of Chicago Press, Chicago, Illinois, 2003), 5.
5) Bruce Walker and Michael Nees. “Theory of Sonification,” in *The Sonification Handbook,* eds. Thomas Hermann, Andy Hunt, John G. Neuhoff (Berlin: Logos Verlag, 2011), 7.
6) Perry R. Cook. “Sound Synthesis for Audio Display,” in *The Sonification Handbook,* eds. Thomas Hermann, Andy Hunt, John G. Neuhoff (Berlin: Logos Verlag, 2011), 232.
7) Berger, Jonathan and Grond, Florian. “Parameter Mapping Sonification,” in *The Sonification Handbook,* eds. Thomas Hermann, Andy Hunt, John G. Neuhoff (Berlin: Logos Verlag, 2011), 363.
8) Visda Goudarzi. “Designing an Interactive Audio Interface for Climate Science,” *IEEE MultiMedia* 22, no. 1 (Jan.-Mar. 2015): 41-47.
9) Aleksandra Samolov. “Analysis of Just Noticeable Difference in Spectrum of Church Bell Sound”. *Telfor Journal* 2, no. 2 (2010): 82.

10) McGookin, Daniel and Brewster, Stephen. "Earcons," in *The Sonification Handbook,* eds. Thomas Hermann, Andy Hunt, John G. Neuhoff (Berlin: Logos Verlag, 2011), 340.
11) Walker and Nees. "Theory of Sonification", 20.
12) Grond, Florian and Hermann, Thomas. "Aesthetic Strategies in Sonification". *AI & Society* 27 (2012), 214.
13) Simon Emmerson. *Living Electronic Music.* (Burlington: Ashgate Publishing Company, 2007), 5.
14) Eric Johns, interview by author, Riverside, CA, October 18, 2015.

CHAPTER 4: FROM AUDIFCATION TO SONIFICATION TO MUSIFICATION: PROCESS AND AGENCY IN USING DATASETS FOR MUSIC COMPOSITION

According to Sinclair, sound artist and research director of Ecole d-Art D'Aix-En-Provence's *Locus Sonus* sound lab, "sonification is the natural step in the evolution of music… in sonification for art, the choice of the data to be used is fundamental, often serving as the conceptual mainstay of a piece". [1, 2] In the following chapter, I share my personal experiences as an artist working in concert with the biological, process-driven medium of compost and the issue of exercising my own creative agency in manifesting two traditionally-scored music compositions for acoustic instruments—*Desert Winter* (2014) and *Sweeney Summer 2* (2016). *Desert Winter* was developed as an initial study during my two-year research period, and reflects the process of devising a methodology for generating a basic temperature profile of the biota, the development of a temperature sensing apparatus, as well my first foray into MIDI note-number parameter mapping. *Sweeney Summer 2* is a mixed chromatic and microtonal chamber piece for three performers based on a portion of the large dataset that was collected between days 7-10 of the gallery-based study.

PROCESS

Steve Reich, in his 1968 "Music as a Gradual Process" states, "the distinctive thing about musical processes is that they determine all the note-to-note (sound to sound) details and the overall form simultaneously". [3] The act of sonifying temperature relationships within the biota can be seen in itself as a performative and multi-layered process, while music generated through data sonification aligns most closely to the genre of process-based composition. Reich's above assertion rings true for almost all sonic realizations developed during *Composing [De]Composition.* The Hertz-based audified soundscape created at the *Sweeney Art Gallery*, the microtonal MIDI note number sonification presented at the Data Listening Session, and *Desert Winter*—the work for solo piano discussed below—all closely followed the temperature dataset. In the case of the chromatic mapping used for *Sweeney Summer 2,* however, additional scaling adjustments had to be made due to incongruencies between the raw data values and the pitch ranges of the acoustic instruments used.

In the same essay, Reich also asserts that

> [In order] to facilitate closely detailed listening, a musical process should happen gradually… By 'gradually' I mean extremely gradual; a process happening so slowly... that listening to it resembles watching a minute hand on a watch—you can perceive it moving after you stay with it a little while. [4]

Reich's approach of stretching the diachronic envelope to enact a musical process is indeed extremely revealing when used in the context of a live, acoustically-based performance. However, when it comes to data sonification, what takes control in the realm of human perception is the timescale of changes needed to percieve the phenomenon being examined. For example, if working with a dataset based on tracking changes within a nano-process related to particle physics, slowing down the data playback rate makes the most sense in terms of scale of human perception. Conversely, in the case of *Composing [De]Composition*'s data playback and listening session, the opposite of Reich's thesis proved to be true. Since the process of change in compost temperature already stretches out over hours, days, and even months, *speeding up* the data playback rate facilitated perceptible changes for listeners. Playback of the entire 30-

day dataset at the same rate it was audified would, of course, take 30 days, and analysis of temperature changes would be difficult. Through the use of accelerated time scaling, however, patterns of change were very easily detected. For example, when playback speed was increased to the read rate of 1 data point per 45 milliseconds—*twenty-two times faster than real-time*—temperature changes were heard to *slowly* fluctuate back and forth between tenths of degrees before a new stasis was achieved.

On Developing & Working Acoustically with a Dataset: Desert Winter for Solo Piano

My discussion of the idea of process in relation to *C[D]C* now turns to a brief description of *Desert Winter*, a work created for solo piano based on the 45-day compost temperature study. Already being an experienced composer/composter, yet new to sonification research, this study allowed me to expand my practical knowledge into a more technically-based arena in both areas. Generating my own data allowed me to build my research and the resulting project up from ground zero, first autodidactically developing a methodical, manually based technique for measuring changes in the biota while also maintaining its health. The fruits of this 45-day effort resulted in the development of a highly precise temperature data audification and important insights into the nature of temperature change within the biota. The resulting work for piano charts the evolution of my temperature measurement techniques and tools.

Figure 4.1 revisits the graphed 45-day compost temperature dataset first seen in chapter 3. Here, the y-axis represents temperature and the x-axis the days of the study. Included in this version of the dataset visualization are the temperature measuring tools I used over the course of the study. At first, I used the analog meat thermometer shown. On

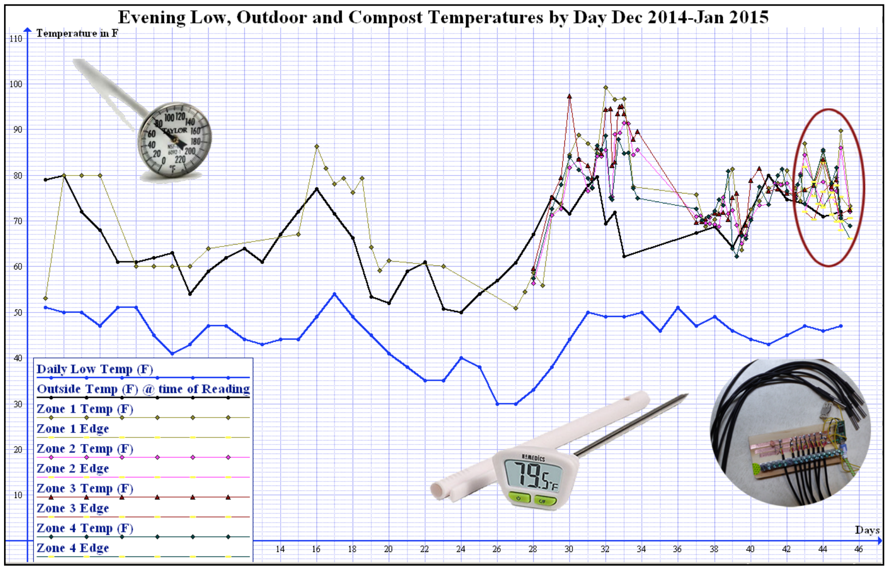


Figure 4.1: Dataset and temperature reading tools used for the creation of *Desert Winter* (2014). At days 43-45 (red circled data points) I begin to record eight temperatures based on the design for the array-based temperature sensing apparatus (inset).

day 28, I began to use the digital meat thermometer illustrated. Instantaneous temperature readings provided by this new tool allowed me to quickly take measuremnts from different quadrants of the biota, and I began to record four temperature readings twice per day. By day 43, the number of readings increased to eight, which influenced the final design of the temperature sensing device shown in the rightmost corner of figure 4.1.

From Dataset to Pitch Set: MIDI Note Number Parameter Mapping

I decided early in the outdoor study that the compost would be audified in real-time as a Hertz-based soundscape using the basic versions of the MAX/MSP audifcation patchers described in chapter three's section on data audification. For my first foray into sonification, I elected to experiment with the process of manually mapping the data to MIDI note numbers. To achieve this, I kept a handwritten master record of temperature data collected from the compost. To further contextualize the biota as situated in a greatly fluctuating outdoor desert environment, I kept a journal of outside air temperatures at the times of biotic measurement, and also sourced online daily low temperatures in my area.

Figure 4.2 illustrates how I organized each day's data collections into a large chart indicating (reading from the right) (1) the day of the study; (2) associated temperatures recorded in one to eight zones of the compost; and (3) two columns indicating outside high and low temperatures. I also integrated corresponding scientific pitch notation for each numerical value listed with the associated temperature readings. The illustration shows data collected in four zones, with temperatures recorded at least twice daily between days 32-33.

Once I began using the digital meat thermometer, it became clear to me what a dynamic system I was working with. Oftentimes, as I took temperature readings the digital meat thermometer would fluctuate up and down in value, while at other times temperature readings would be stable. I thought this aspect might be interesting to sonify,

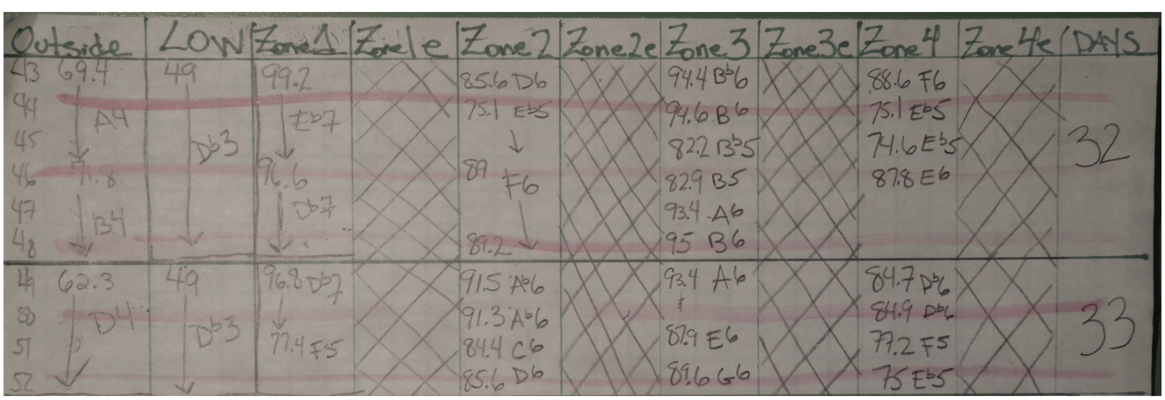
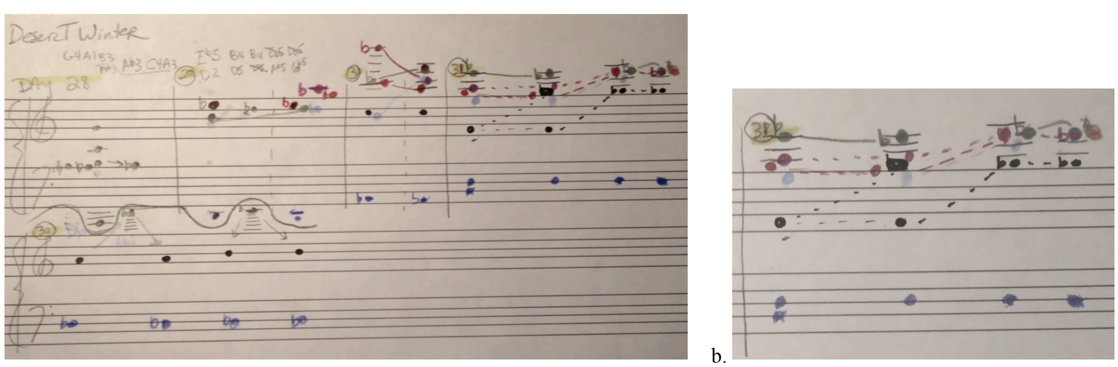


Figure 4.2: Part two of the process in developing the methodology for temperature recording was manually creating this chart for the analysis of the various data. Temperature shown at the left, while scientific pitch notation is shown to the right of the temperture values.

so I decided to record all temperatures I saw until the device settled to a steady value. Multiple entries seen at Figure 4.2/Zone 3 show such fluctuation. As mentioned above, at day 43 of the study I began recording eight temperature readings for each session.

After the data was organized, my next challenge was devising a way to render the data into an understandable system of Western notation for human players. First, I created daily pitch groups based on the master data chart. Figure 4.3(a) shows a sketch of this part of the process for days 28-32 of the study. While the compost and daily high outdoor temperatures mainly occupy the treble clef, outdoor temperatures remain firmly in the bass clef. Seeing the temperatures organized as daily pitch collections was a crucial step in my conceptualizing the data musically. For example, when faced with multiple temperature values recorded during a single reading—as seen at day 31 in Figure 4.3(b)—writing all the information out on the staff paper aided me in reimagining the zone-specific temperature fluctuations as being rhythmic and forming a sort of harmonic motion.



a. b.

Figure 4.3: (a) Pitch groups for days 28-32 of the 45-day outdoor compost temperature study; (b) detail of day 31's resultant four pitch groups. Different pitch groups indicate fluctuations in the digital thermometer during the temperature recording session. Pitches in the bass register represent daily low temperatures.

Writing for the Piano

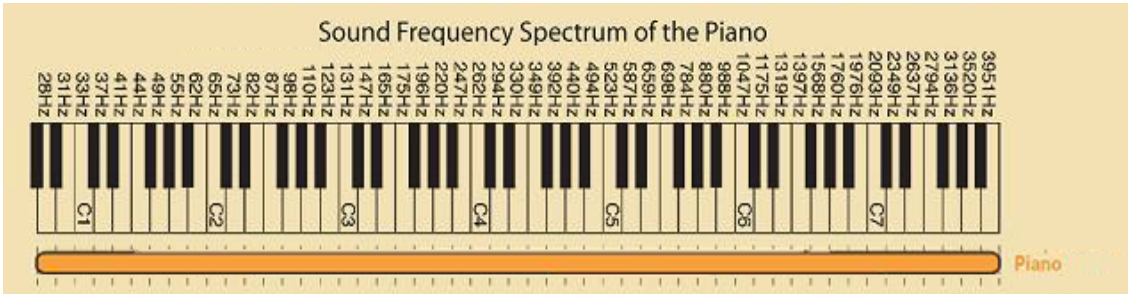


Figure 4.4: The sound frequency spectrum of the piano.

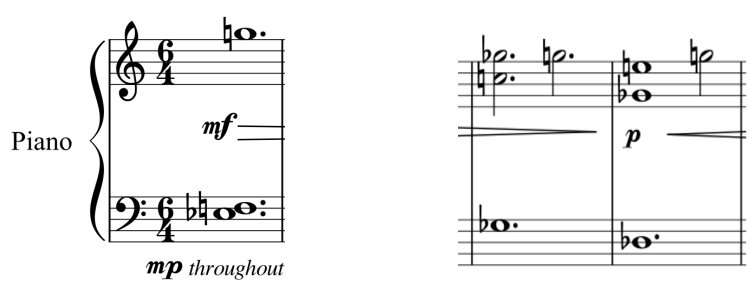
The opportunity to develop and test a dualistic approach for parameter mapping in the Hertz-based soundscape versus the MIDI note number Data Listening Session allowed me direct investigation into different ways of deploying the dataset. Given the combined pitch range of the piano (Figure 4.4), and the player's ability to sound multiplex pitch information, it was an excellent choice for to use as a solo instrument in an acoustic instrument-based study. The only drawback to using a solo instrument in comparison to a spatialized audio display was the fact that all differentiation between temperature zones was lost.

According to Walker and Kramer, "it is important to know how well listeners will be able to listen analytically to one stream (or substream) at some times, and listen holistically (integrating across streams) at another" [5] in a data sonification. When played by a single instrument—even one that can execute multiple voicings, listeners can only gain a holistic experience of the data, and not a completely analytical one. Hence, when compared to a spatialized, digitally-based sonification, the effectiveness of this acoustically-based work as a sonification was greatly diminished. I prefer to think of this type of work as a "musification" using parameter mapping, rather than as a strict sonification. Where sound and data can be very tightly coupled in a sonification, the process of musification usually results in a more abstracted rendition of the dataset. I discuss the distinctions between musification and sonification in more detail below in the section describing the development of *Sweeney Summer 2*.

Developing the Score

The final score for *Desert Winter* (found in the Appendix A) was realized primarily in 6/4 meter, with modulations to 3/4, 5/4, and 2/4 meter as the work progresses. The approximately seven-minute piece consists of 61 measures with repeats of material occurring three times in various areas of the musification to highlight particular tonal and rhythmic interest. Measures 53-61 are not based on actual data collected, rather, they are used to act as coda to the work—referencing the slow, harmonic rhythm first experienced at the beginning of the study.

Daily low outside temperatures were translated as whole notes occupying the bass clef, while the outdoor air temperature readings taken at the time of compost measurements consist of either whole notes, as shown in Figure 4.5 (a), or split up as dotted half notes. This organization reflects the point in the 45-day study when I began to



a. b.

Figure 4.5: *Desert Winter* (a) Mm. 1-3; and (b) mm. 16-17.

take multiple temperature readings per day in the compost (Figure 4.5b mm 16-17)—reflecting my growing awareness of the biota as a dynamic mass.

As mentioned above, by day 28 of the study, I began recording four compost temperature readings in separate temperature zones at two different times of day. This increased amount of data required me to develop a more complex way of notating change within the biota. Following the trajectory of aligning musical rhythm to my growing collection of temperature information, I began to think of the actual changes in the biota as rhythmic. For example, Figure 4.6 below shows mm. 30-31 of *Desert Winter*. At m. 30, I indicate rising temperatures during the data collection as a slow, arpeggiated chord that falls tonally inward for the second half of the measure, while at m. 31 the initial chord takes on an upward motion for beat one and the first half of beat two, followed by an upward consolidation of temperatures—indicated by the decreased number of pitch materials and the new presence of F_4 in the chord beginning at the second half of beat two. At beat four, pitch space becomes even more compressed while arpeggiating upward—finally settling into a dyad for the second half of beat five.

By day 43-45 of the study, I decided to measure each of the biota's four temperature zones at its center and edges. This doubling of data points pushed the

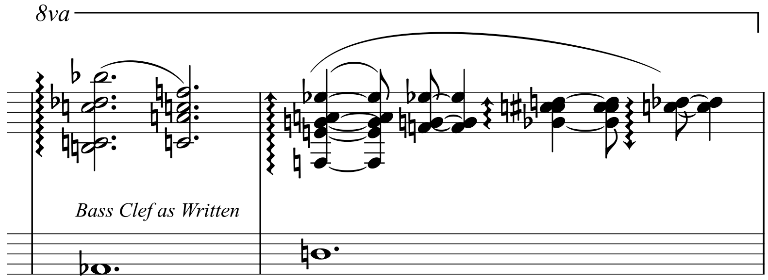


Figure 4.6: *Desert Winter* mm. 30-31 illustrate various rhythmic approaches toward musically notating temperature change in the biota.

rhythmic trajectory of the musification to its highest complexity. Now with eight temperature zones and corresponding changes to map, I decided to break out of the initial one day/measure metaphor originally cast—switching meter to 3/4 and dividing the changes in pitched material for the day between two measures. Figure 4.7 shows this new approach using 3/4 meter in mm. 43-44 contrasted with m. 42's setting of 6/4 meter. Measured repeats are also used here to draw attention to the new meter as well as the thicker pitch complex.

The fact that this study was executed during the early stages of the temperature sensing apparatus prototyping period turned out to be an unexpected boon. The experience of working with a gradually increasing amount of data enabled me the mental space to develop and explore different rhythmic, and temporally-based mappings of the data recontextualized as pitch. I found that with the gradual increase of data points over the course of a single day, the rhythm of the musification became more complex resulted in a more gestural musical interpretation of the biota's dataset. In addition, the

Figure 4.7: Mm. 42-44 of *Desert Winter* illustrate how a change in meter is used to signify a new stage of the compost temperature study, where eight simultaneous temperatures were recorded at all times. M 42 is in 6/4 meter while mm. 43-44 are realized in 3/4. Duplicate temperatures found in neighboring zones are also reflected as chords with less than eight pitches.

integration of data pertaining to outside air temperatures as pitched pedal points served to contextualize he biota within its surrounding environment, while also grounded the overall musification tonally.

AGENCY

At first, the thought of working with predetermined datasets may seem to leave no room for the composer's own creative agency. In actuality however, agency immediately takes a primary role in the artist's determination of what type of dataset is even worth sonifying. An equally important agential decision left entirely up to the composer working with datasets lies in determining the desired end goal of the work.

For example, datasets have been adapted verbatim as the basis an entire musical work or simply used as a point of departure for others. Moreover, the challenge of interpreting data allows the composer many options concerning overall aesthetics, as well as areas of focus and exploration (such as rhythm, pitch, dynamics). Depending on the end use of the finished work, it is also possible that a dataset can be enhanced, and even extrapolated upon.

In the case of *Composing [De]Ccomposition*, the fact that I chose to focus on compost temperature data in reflects my engagement with issues of personal resource management and sustainability. The fact that Guillaume Potard decided to sonically distinguish civilian and military body counts in his *Iraq Body Count* sonification was clearly a political statement; and Andrea Polli's interest in sonifying local weather systems was to promote environmental and social awareness of climate change. Moreover, Quintron's choice of sonifying local weather patterns in his local area is (as the sonification is continually running) in the interest of fostering the health and emotional well-being of others.

Although working with data for the purposes of sonification can be closely aligned with Reich's rigidly process-based and deterministic generation of form and material discussed above, composer John Cage's (1912-1992) approach toward music has also made a significant contribution toward the methodologies of many sonificationists. Composer, educator and instrument builder Scot Gresham-Lancaster believes that John Cage's process-based work has made a significant contribution toward the approach of many sonificationists,

> A theme that is running through the theoretical context related to the origins of many sonification projects… [has been] guided by the work of composer John Cage. The simplicity and rigor of his approach to the use of process as a compositional determinate has been well documented... The impact of the direct use of material and the "recipe"-based nomenclature of much of his work codifies an approach that regarded composition as a means of discovering the functioning of the natural world through sound. The resulting examination was manifested as procedural musical compositions full of surprise and beauty. It is important to note that he insisted that the processes outlined in the performance of his scores were to be followed exactly and without the addition of any improvisation to the structure… These compositions show us how we know the world by the way we react to sound elements that are presented in this manner. His work opened the threshold between noise and music, between everyday sound environments and composition.[6]

Similar to Greshan-Lancaster, Sinclair also credits the work of Cage to be of influence to artists working with datasets. Instead of focusing on the issue of process as Gresham-Lancaster does, Sinclair focuses on issues of agency when speaking of Cage. Rather than restricting the composer's creative agency, "the use of data… [can be] considered as a counterpoint to personal choice, and as such, refers to artistic positions which reflect on determinism and freewill as deployed by landmark composers such as John Cage and Iannis Xenakis".[7]

Cage confessed in many of his own writings about music that his aesthetic attitudes

> had nothing to do with the desire for self expression, but simply had to do with the organization of materials. I recognized that expression of two kinds, that arising from the personality of the composer and that arising from the nature and context of the materials, was inevitable, but I felt its emanation was stronger and more sensible when not consciously striven for, but simply allowed to arise naturally. I felt that an artist had an ethical responsibility to society…[8]

Cage saw his role as artist/composer as an agential and social one—whose purpose was to bring together the world's people and its resources through active engagement between art and technology. In the 1969 essay, "Art and Technology" Cage states,

> The purpose of art is not separate from the purpose of technology… (They) bring people together (world people), people and their energies and the world's material resources, energies and facilities together in a way that welcomes... discovery and takes advantage of synergy, an energy greater than the sum of the several energies had they not been brought together. [9]

Sonification's capacity to synergize art, technology and data as a multimodal experience enables society to better perceive the world around them. To this end, sonification challenges listeners to enter a new way of listening—not one governed by any type of music theory, but similar to the completely-in-the-moment experiences of sound and music that Cage first introduced—inviting audiences to claim an agential role in defining and experiencing it. Cage points to this attitude in his 1989 essay, "An Autobiographical Statement":

> We are living in a period in which many people have changed their minds about what the use of music is or could be for them. Something that doesn't speak or talk like a human being, that doesn't know its definition in the dictionary or its

> theory in schools, that expresses itself simply by the fact of its vibrations. People paying attention to vibratory activity, not in relation to a fixed ideal performance, but each time attentively to how it happens to be this time, not necessarily two times the same. A music that transports the listener to the moment where he is.[10]

Spanning across scores of years, Cage's message is one of looking outside the world of ego-driven and absolute music toward how art and music can be of aid to society. Cage invites us—through his music and writings—to view music not as a rigidly codified system of language, but *as a moldable, vibration-based technology* able to transport listeners toward new understanding of the world.

In Cage's work, the process rigidly determines the musical results, however, Sinclair sees sonification as a counterpoint between processual rigidity and compositional agency. I argue for a third point of view—one that *combines* the attitudes echoed above to also include ideas brought forth in chapter two—regarding the collective agency of humans, non-humans, and the techno-ecologies involved in the sonified/sonifying process. I take this stance namely because of my phenomenological experience generating the dataset used for *Composing [De]Composition*.

The creator(s) of many other data sonification works source their data online, or work in tandem with scientists who develop the datasets. Contrastingly, in the case of *C[D]C,* I first physically created the biota, the tools and methodologies for its sonification before translating its incalescent characteristics into sound. Interestingly, my process also required me not only to generate the dataset through its collection and organization, but also through direct, physical interaction with the biota. The design of the sensing array necessitated its removal from the pile prior to aeration. Consequently, the evidence from my weekly necessity to 'feed' and manually aerate the biota to ensure its health—the human mediated, physical, 'process of composting'—was also included/recorded in the dataset.

It was only after visualizing the nearly 350,000-point dataset shown in Figure 4.8 at the end of the data collection period that I fully realized how much my interaction with the biota actually shaped the study's overall results. Figure 4.8 shows a graphic representation of the final dataset for the compost sonification study housed at the UC Riverside *Sweeney Art Gallery.* Here five compost feeding/areations are clearly demarcated as sudden drops in temperature profile across all zones at days 7, 10, 17, and 23.

The action of feeding/aeration not only made for interesting incalescent patterns produced by the biota—which was expected—but the relatively regular removal of the sensors from the biota also allowed me a window into analysis of the environment surrounding the container. The lowest temperature recorded during the aeration/removal period directly references the gallery's ambient room temperature. Additionally, these 'breaks' in the continuity of the biota-driven portion of the temperature dataset made such an incredibly large collection of datapoints much easier to deal with, as each smaller section could be analyzed for highest and lowest temperatures reached, time span, etc.

In this light, it is also important to realize that the compost was not *completely* responsible for the overall form of the final sonified works produced for *C[D]C*. The dataset also represents the complex network of interactions between myself, my mentors, the microbes, rotting vegetables, the environment in which it was placed, etc. In the end, the work was the product of an intense, multi-layered process of which my own agency-

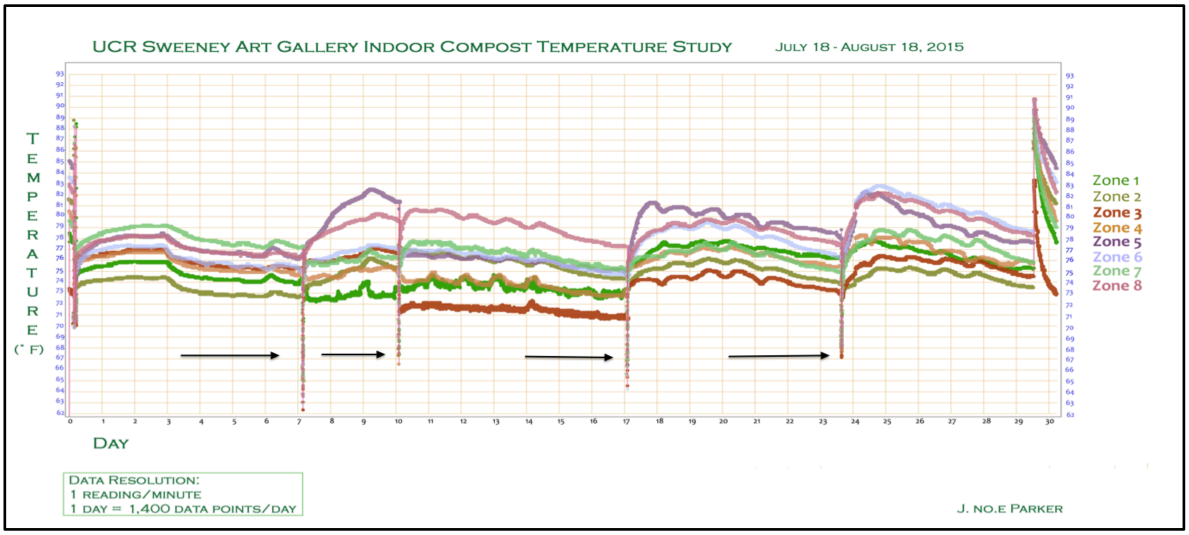


Figure 4.8: Visualization of compost temeperature data recorded during the 30-day, Sweeney Gallery based study. Black arrows show when the temperature sensing device was removed from the biota. Lowest values reflect the gallery's room temperature and not that of the biota.

based actions also played a large role in determining the project's relative success or failure.

From Bin to Graph to Score: the Influence of Morton Feldman's Time Canvas on Meter and Rhythm in Sweeney Summer 2

Although the focus of this study primarily lies in data sonification, I found that creating musified works for acoustic instrumentation also greatly depended on my ability to visualize the dataset. Looking at the compost temperature data as a graph—plotting time versus temperature—allowed quick analysis and contemplation of the material in the musical realm. Form, structure, and pitch profiles/trajectories could begin to be fleshed out.

Music composition based on graphic depiction is not new, by any means, however I would like to take a moment to ground my study in context of the pioneering graphic work of Morton Feldman (1926-1987). Feldman is an American composer who has been credited with the development of time-grid based graphic notation. According to him, "the moment a composer notates musical thought to an ongoing ictus, a grid of sorts is already in operation, as with a ruler". [11]

Over the course of his life, the composer was closely aligned with the New York School of modernist painters such as Robert Rauschenberg, Mark Rothko, and Jackson Pollock. In the words of Feldman,

> The musical ideas I had in 1951 paralleled [Jackson Pollock's] way of working. Pollock placed his canvas on the ground and painted as he walked around it. I put sheets of graph paper on the wall; each sheet framed the same time duration and was, in effect, a visual rhythmic structure. Usual left-to-right passage across the page, the horizontal squares of the graph paper represented the tempo—with each box equal to a pre-established ictus; and the vertical squares were the instrumentation of the composition. [12]

Projection 2 (1951) is one of Feldman's earliest efforts in using a graphically based time grid for music compostion, and is part of a series of five, graphically-notated works that were developed by Feldman between 1950 and 1951. Examination of Feldman's score for *Projection 2* in Figure 4.9 allows the reader to immediately conceptualize the composer's idea of "time–canvas".

The music for *Projection 2* is set in a grid-based graphic score consisting of 85 horizontally oriented boxes that are mapped out along an implied temporal plane. Interestingly, the score for the work has no indicated time signature, however a suggested overall fixed meter of four pulses per grid set to a tempo of 72 beats per minute is suggested in Feldman's performance notes. Feldman clearly constructed *Projection 2* based on his suggested four ictus/grid box schema, as there is clearly no smaller

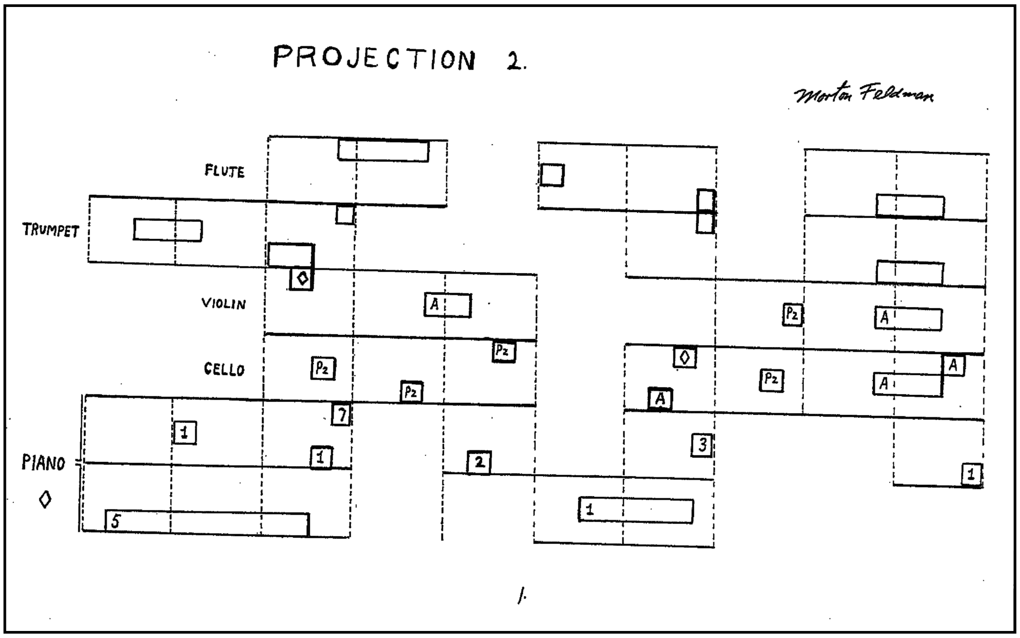


Fig 4.9: Page one from Morton Feldman's *Projection 2* (1951).

subdivision that is visually proportional to the 4:1 ratio anywhere in the entire eight page score.

Although *Projection 2* is orchestrated for flute, trumpet, violin, violoncello, and piano, Feldman does not concern himself with the exact pitches of the instrumental soundings of the work in a traditionally-notated sense. Instead, the composer only indicates that the ranges of high, medium and low to be played with durational values for each sounding relative to the length of a horizontal bar placed at the intersection of the row indicated for each instrument and the dotted lines of the temporal grid. Due to Feldman's non-specificity of pitched material in *Projection 2*, it is clear that Feldman's work in the graphic realm at this point in his career was deeply rooted in the phenomenology of sound making, rather than creating a reproducible artifact. In the essay, "Liner Notes", Feldman states that

> The new painting made me desirous of a sound world more direct, more immediate, more physical than anything that had existed heretofore… *Projection 2* for flute, trumpet, violin and cello—one of the first graph pieces—was my first experience with new thought… The new structure required a concentration more demanding than if the technique were that of still photography, which for me is what precise notation has come to imply. My desire here was not to "compose" but to *project* [my emphasis] sounds into time, free from a compositional rhetoric that had no place here. [13]

Feldman's attitude regarding the use of indeterminate pitch materials in *Projection 2* is of course in stark contrast with data sonification's goal of interpreting definite information. However, sonifications very closely align with Feldman's above desire in that they free the composer "to project sounds into time, free from a [music-theory based] compositional rhetoric".

The Underlying Chronometric Grid of Sweeney Summer 2

While Feldman's time-canvases were the composer's response to the work of his contemporaries in the New York school of abstract-expressionist painters, my use of the graph in *Sweeney Summer 2* grounds the work in two ways: (1) it provided a very direct means of visualizing and mentally accessing an otherwise unmanageable amount of information; (2) it formed the very foundation for expressing a real, chronometrically-recorded organic process. *Sweeney Summer 2* is a 24-measure chamber piece in 6/4 meter for violin, percussion and piano. The work is based on a portion of the dataset collected between days 7-10 of the study—a three-day period between the biota's first and second feeding/ aerations. Figure 4.10 shows the 30-day dataset highlighting the data I

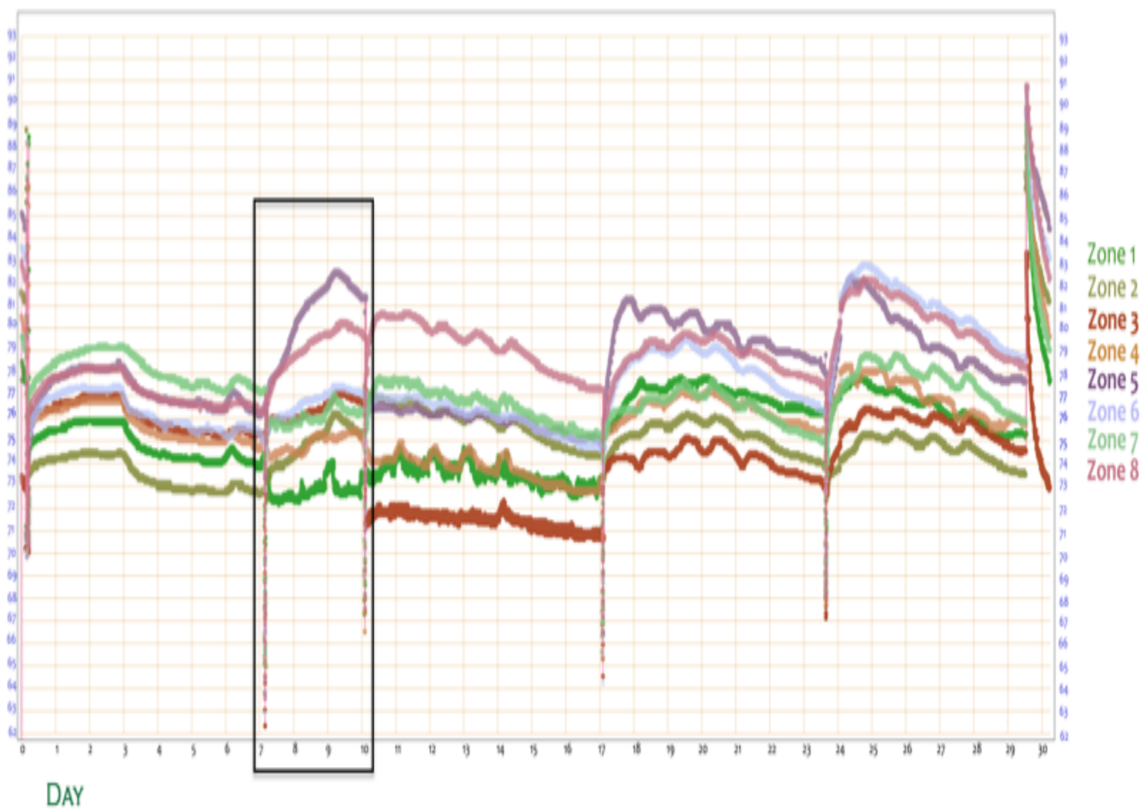
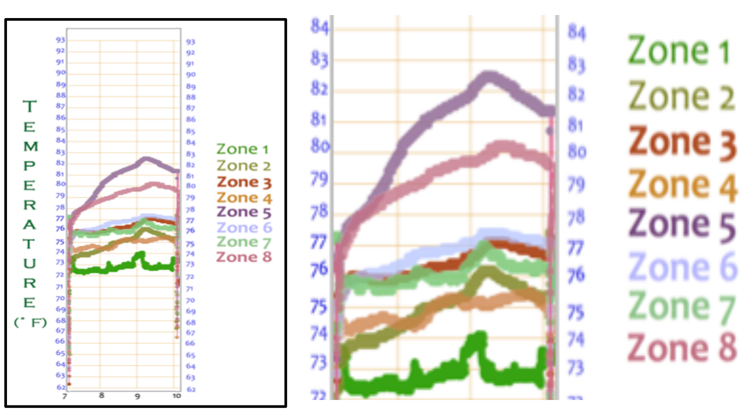


Figure 4.10: The 30-day compost temperature dataset. The area inside the black box is the portion of the dataset I chose to work with in the development of *Sweeney Summer 2*.

a.



b.

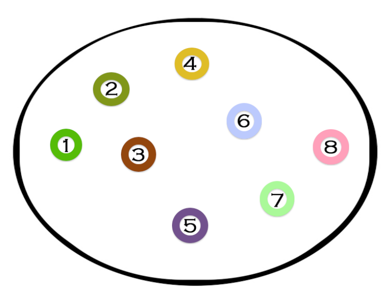


Figure 4.11: (a) Detailed views of days 7-10 of the compost temperature study; (b) Approximate positioning of each temperatre sensor in the biota, with corresponding zone. Colors identify the trajectory of each zone's temperature chages in Figure 4.11a.

specifically chose to work with for *Sweeney Summer 2* as outlined by a rectangular box. Figure 4.11(a) shows a more detailed view of that section, while Figure 4.11(b) contextualizes the temperature zones with respect to where they were situated inside the gallery's compost container. Maximum temperature changes during days 7-10 occurred in zone five (approximately 10.5 degrees), while only a total change of 1.5 degree was recorded in zone three.

Designing a Grid-Based Meter

The underlying chronometric grid provided by the data visualization above made things quite straightforward for mapping the data into a metered musical score. However, the first challenge in musifying the dataset arose immediately when I set about the task of rendering and translating the dataset from such a high resolution and rate of change into a form more executable for human performers. It made no sense to map entire days to measures as the study only lasted three days, so a different time-based division had to be developed.

Consideration was given to either using 4/4 or 6/4 meter for final the work as both 6 and 4 divide evenly into 24 (hours). Figure 4.12 shows how each of the aforementioned different meters map out rhythmically in a notated score. It is my feeling that setting the material in 4/4 meter lends an underlying urgency to the resulting musification, and while a setting of 6/4 meter paired with the tempo marking of ♪ = 80 better reflected the slow process of decomposition (at least as it is perceived on the human scale). Using 6/4 meter

Figure 4.12: Two different temporal matrices considered for contextualizing the data. 4/4 meter works out at six 16th notes per beat, while 6/4 meter works out at four 16th notes per beat.

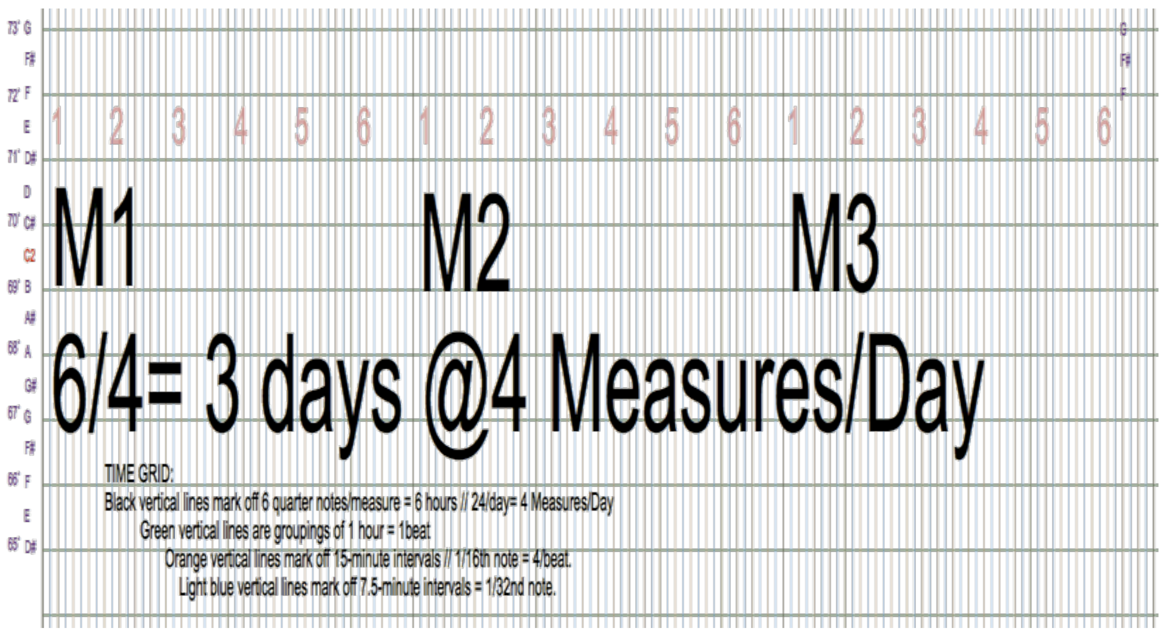


Figure 4.13: Metric grid developed for the data musification *Sweeney Summer 2.* 1beat/hour @ 24 beats/day = 4 measures/day.

allowed me to split up each 24-hour day of the study into four, six-beat chunks.

Figure 4.13 shows the overall layout of the metric grid used for *Sweeney Summer 2* with references to both musical and chronographic time. After the work of metric setting was completed, I turned toward devising a way to quantize down the extremely high resolution of the dataset into a more playable realm for humans. Although high-resolution data collection is an integral aspect to any time series based sonification study, the fact that there were 1,400 datapoints collected for each sensor/day made the dataset way too large to be executed by human players.

Figure 4.14 shows the extreme rhythmic detail rendered by the dataset superimposed onto the 6/4 grid. The red numbers section off each individual beat. Beginning with the box numbered ‘1’, eight vertical lines count over to the beginning of the next beat. Using this grid, individual vertical lines = 𝅘𝅥𝅯 and every two lines = ♪. However, the resulting beat mapping was still too small to translate rhythmically for live performance. In light of this, I simply doubled everything in value—reassigning each grid the value of ♪in the actual score. This caused the original 12-measure mapping to extend out to 24 measures. Hence, the material shown in the graphic version of the dataset in Figure 4.14 occurs at mm. 13-14 of the score.

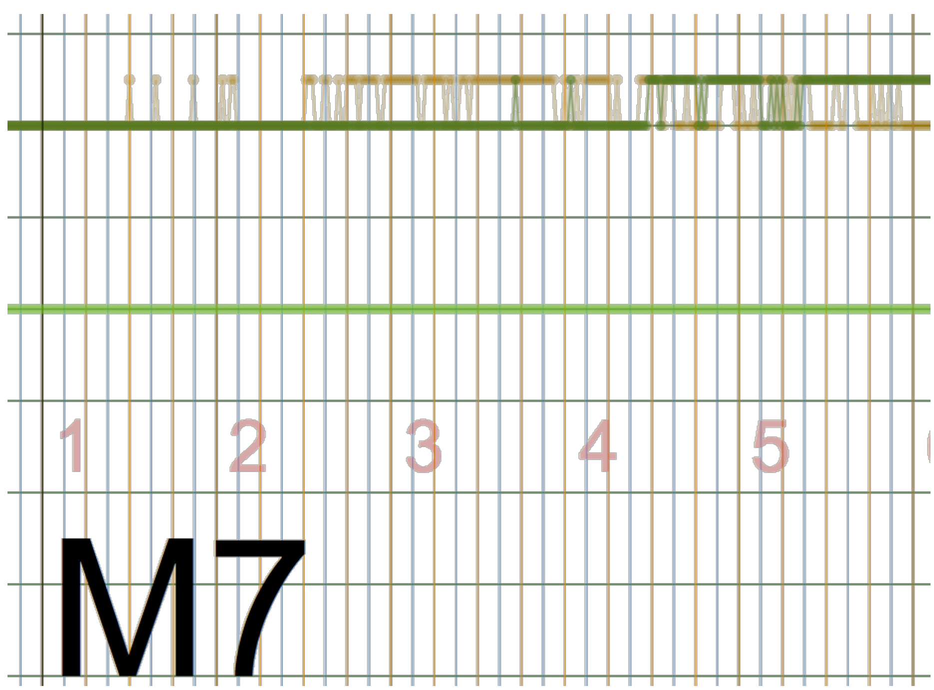


Figure 4.14: Extremely detailed view of data mapped onto 6/4 meter: m.7 beats 1-5. Even at this resolution I needed to double rhythmic values in the score. After doubling, this mateial is found in mm. 13-14 of the notated score.

In the end, it was the biota's *rhythmic process* of temperature change, rather than the *increment* of change that interested me the most about this study. Devising ways to translate temperature changes that I had seen in the graphic representation of the data—as seen in the top two lines at m. 7 of Figure 4.14—into rhythmic, musical gestures was not only intellectually challenging and fun, but these gestures are what gave life and body to the piece. But first, I will lead our discussion into the realms of pitch and instrumentation before I reveal anything further about the rhythmic material of the final score.

FORMING AN ONTOLOGY: MAPPING DATA TO ACOUSTIC INSTRUMENTS

Informationally speaking, a microtonal rendition of the dataset makes the most sense in a sonification work where the tonal area only modulates a maximum of 11 semitones (26 when using a quartertone scaling) in one voice, and three in another. Thus, the task of placing the data in a setting for an acoustic chamber ensemble revealed a second challenge in trying to create a work closely related to the data. Due to the fact that acoustic instruments each have their own unique physical limitations—such as the available pitch range and the ability to play more than one tone simultaneously, for example—I found that the process of mapping the dataset transformed from a very literal one to an ontological one.

Before setting about the challenge of devising a way to render the dataset into Western notation/acoustic instrumentation for human players, I needed to develop an ontology for mapping the dataset to the different instruments aligning the resulting sonification as closely with the dataset as possible. I achieved this task in a multi-layered process. Figure 4.15 illustrates the frequency spectrum of the violin, piano, and

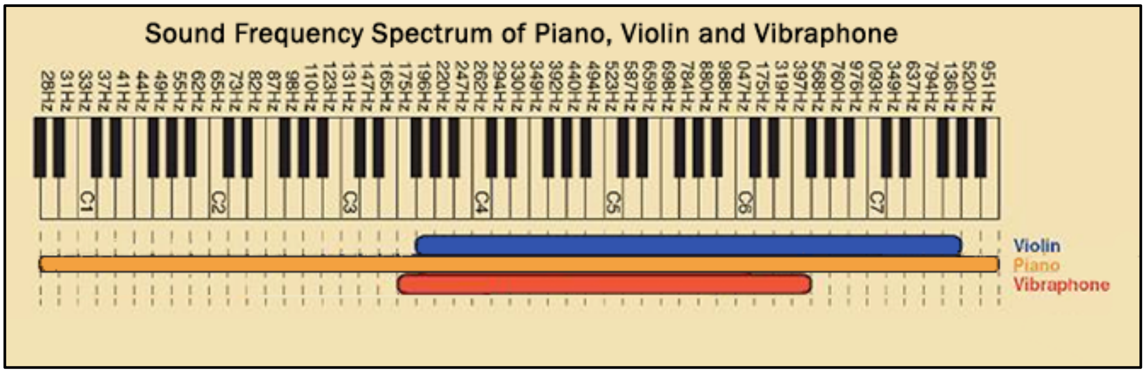


Figure 4.15: The sound frequency spectrum of instruments used in *Sweeney Summer 2* guided my primary decisions in rescaling the dataset.

vibraphone. Using this as a guide, I assigned the dataset from the coolest three zones (1, 2, 4) to the piano, and mid- to high range temperatures (zones 3, 6) to the vibraphone. The highest temperature profile (zone 5) was assigned to the violin.

Instead of using the MIDI note number mapping applied in *Desert Winter*, I opted to experiment with rounding off all fractional values of the dataset to varying degrees and then I scaled it into the ranges of the individual instruments. I adjusted the resolution of data used for the piano and vibraphone parts by rounding up to the nearest half degree, and rounded the violin's dataset to the nearest quartertone. While the piano's pitch range begins at A_0 and runs to F_8, the vibraphone and violin have more limited ranges—which proved to be a major obstacle to creating a musification closely related to the dataset.

To offset these differences, the lowest pitch in each instrument's range was assigned to the lowest observed temperature (62˚F) of the study. The choice of this low temperature reflected the average temperature in the gallery, and was measured on day seven after the sensor array was removed from the biota. Subsequent values increased by half steps up to G_5—the highest temperature reached in the study (91˚F). In order to preserve the integrity of at least half of the data being musified, the zones assigned to the piano part remained in this original scaling.

Figure 4.16 shows the datasets for the three voices of the piano rounded to the nearest half-degree and mapped to the chromatic scale. Table 4.1 illustrates all voicings, transpositions, and of the six datasets used for *Varied Trio*'s rendition of *Sweeney Summer 2*.

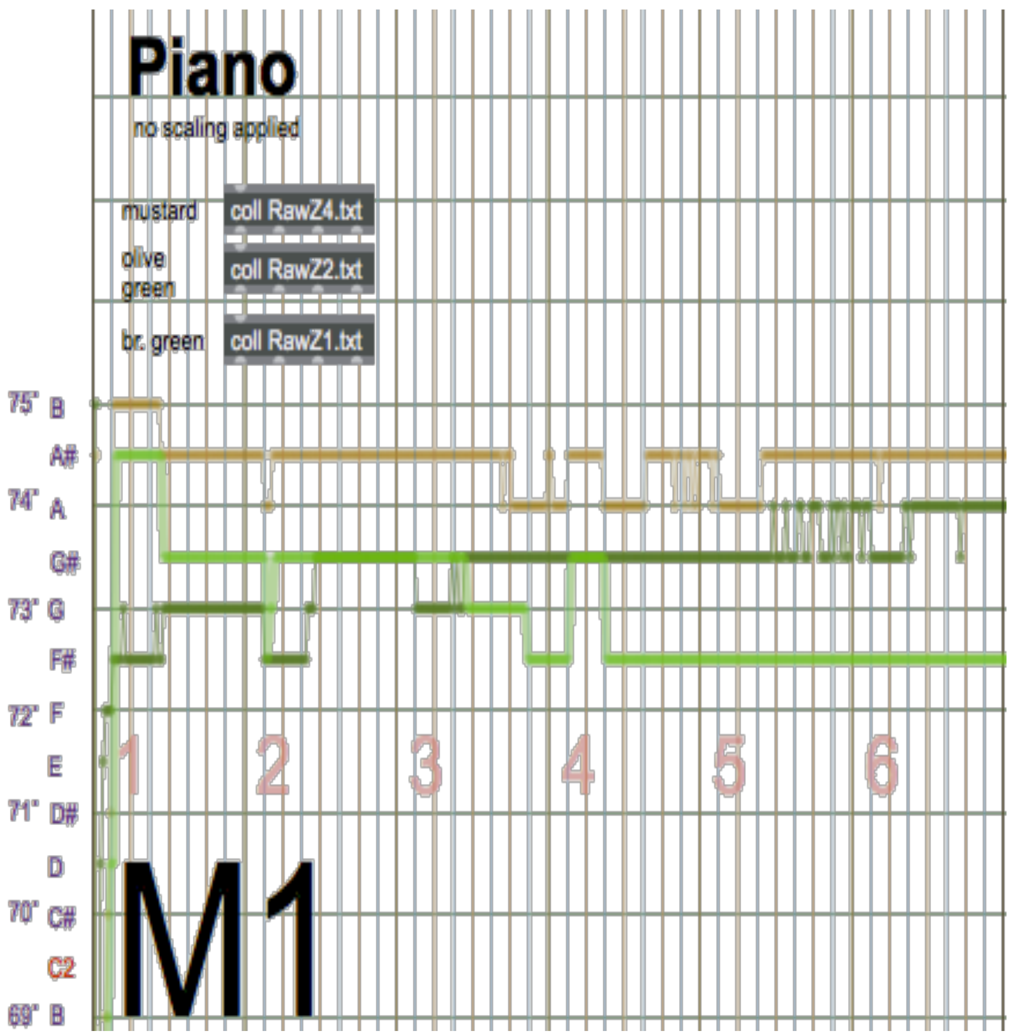


Figure 4.16: Piano data (zones 1, 2, 4) mapped to a chromatic scale starting at A_0=62˚F—the lowest temperature recorded during the study. Note: full chromatic scale not shown here.

Table 4.1

Instrumentation, Voicing, Pitch Ranges, and Transpositions of *Sweeney Summer 2*						
	PIANO			**VIBRAPHONE**		**VIOLIN**
Voices	3			2		1
Zone #	1	2	4	3	6	5
Maximum Variance (semitones)	5	7	3	4	6	11/26*
Pitch Contour (w/o Transposition)	$A\#_2$-$F\#_2$-A_2-$F\#_2$-$G\#_2$	$F\#_2$-$C\#_3$-C_3	B_2-A_2-C_3-B_2-	B_2-$C\#_3$-$D\#_3$-D_3	B_2-$C\#_3$-E_3-$D\#_3$	$C\#_3$-D_4-C_4
Lowest Pitch in Instrument Range	A_0			F_3		G_3
Transposition (semitones)	None			+15	+23	+15
Pitch Contour (w/Transposition)	N/A	N/A	N/A	D_4-$C\#_4$-F#- F_4	D_5-C_5-G_5-$F\#_5$	$F\#_4$-$D\neq_4$ $F\pm_4$-B_4-F_5-$D\#_5$
						*quarter tones

Data Mapping the Vibraphone

Given that the unscaled temperature data for the two zones assigned to the vibraphone (3, 6) was originally too low for the playable range of the instrument, I was forced to transpose pitch materials representing both datasets up by 15 semitones. Performing this transposition frustrated me immensely at first, as it transmuted the concrete relationships between observed temperature zones into conceptual correlations. It was at this point that I had to remind myself that the whole purpose of this composition exercise was conducting phenomenological research into the realms of possibility for

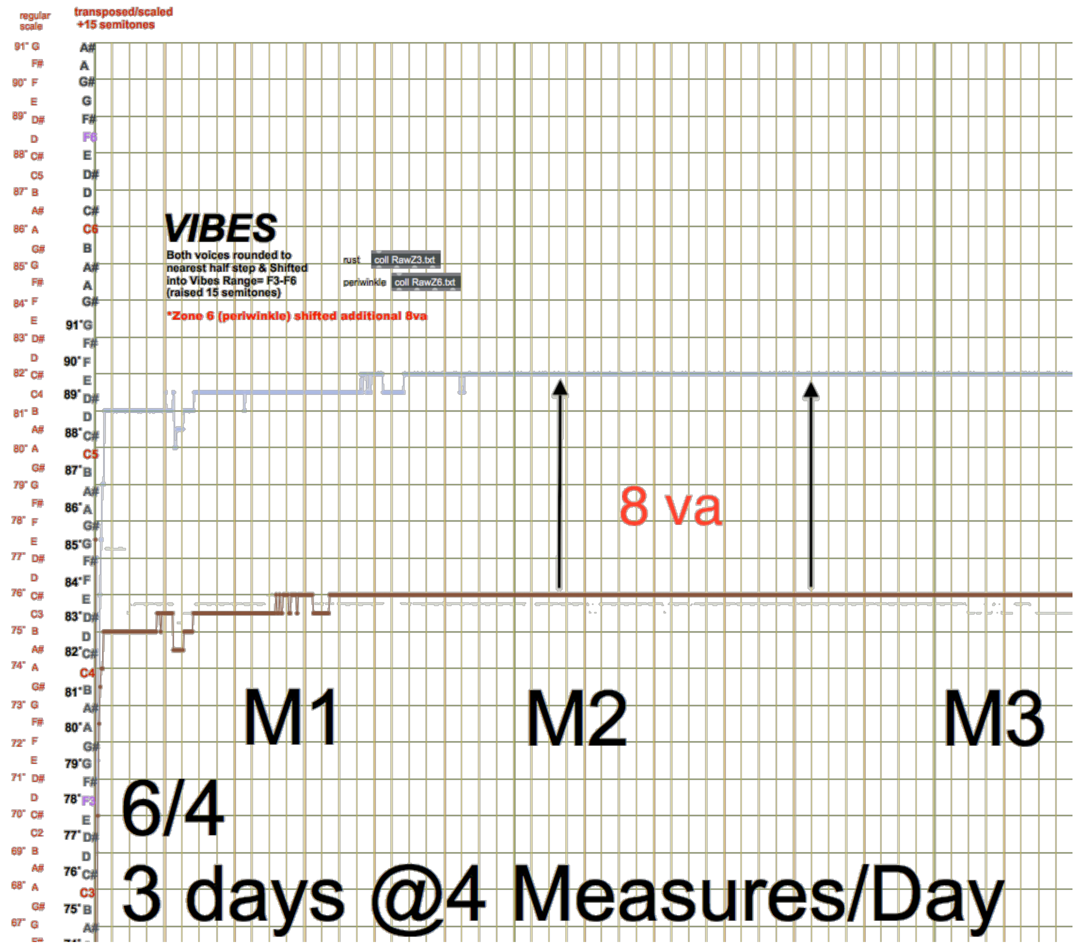


Figure 4.17: Datasets for zones 3, 6 transposed +15 semitones to fit into the range of the vibraphone, while zone 6 is raised an additional octave. Scaling used for the piano is shown in red on the left.

data sonification. I had previously concentrated so much of my time and energies crafting methodologies for collecting and interpreting the data that it was hard to divorce myself even the slightest from a faithful and close translation of it.

Since the temperature values collected in zones 3 and 6 were very closely aligned in the original dataset, I decided to transpose the zone 6 data an additional octave higher—this way listeners could hear the slight changes between voices more clearly, and the vibraphone part would be at more interesting for the performer to play. Figure 4.17

shows the data used for the vibraphone transposed against the red, initial scaling set out for the piano.

The Violin

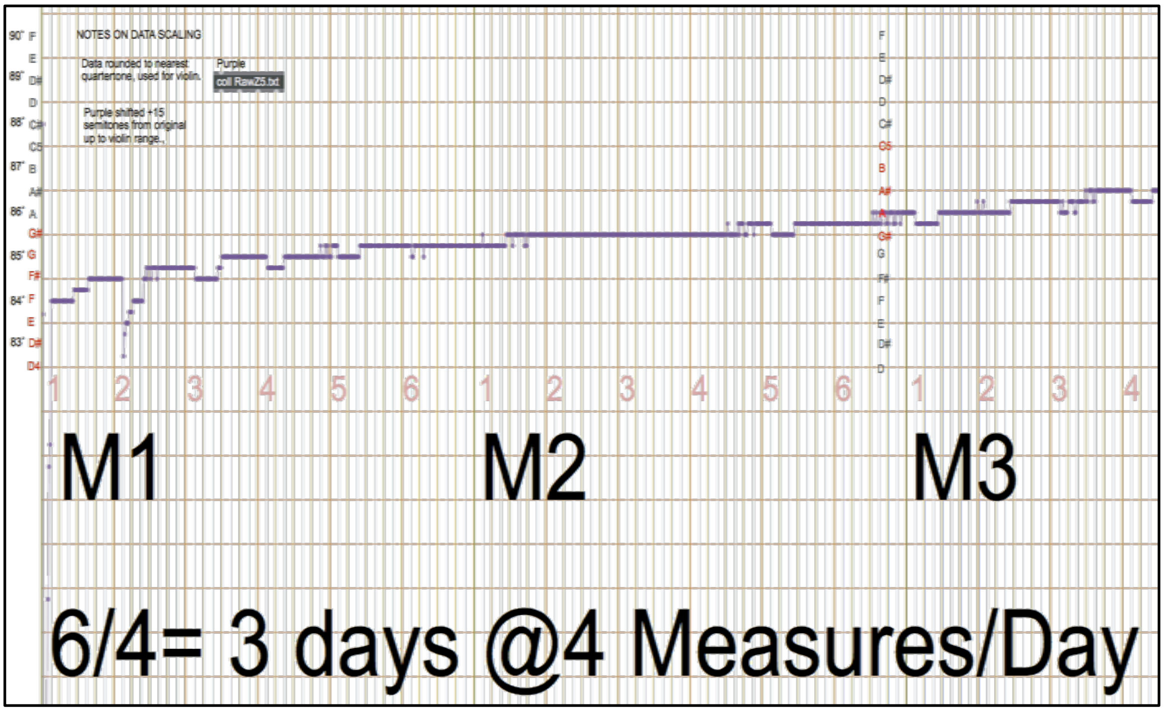


Figure 4.18: The zone 5 dataset was rounded to the nearest quartertone and assigned to the violin.

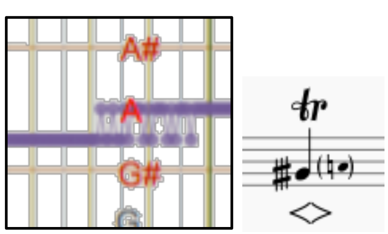
Temperature changes in zone 5 of the biota were the most dynamic of all zones—achieving the warmest temperatures of all areas, and raising up six degrees (translated as an entire octave) in a little over two days—so I selected the violin to portray them. Given that the other instruments were physically tied to expressing a lower-than-actual resolution of their datasets, I also chose to exploit the violin's capability to sound quartertones. This dataset also needed to be transposed up 15 semitones to match the pitch range of the instrument. Figure 4.18 shows the quarter-step pitch mapping used in the violin part of *Sweeney Summer 2*.

Notating Temperature Change with Rhythm, Pitch and Earcons

When beginning this compost temperature sonification study two years ago, I initially imagined changes in the biota's temperature as predominantly pitch-based. Surprisingly, when listening to the dataset playback it turned out that the *process of temperature change* proved to be much more dynamic than the overall resulting pitch profile. In response to this, I focused my musification of the dataset on the gestures created during temperature changes.

These changes were manifested in the score as instrument-specific, non-repeating, stepwise rhythmic gestures rather than anything resembling a melodic contour. For example, to express transient temperature changes between one semitone and the next in the violin, I integrated the use of a series of microtonal trills of varying length depending on what I saw in the graphic representation. To express this same type of change in the piano and vibraphone voices, a combination of half-step dyad tremolos with changing dynamics and speeds were utilized. Figure 4.19(a) shows the graphed data and the

a.



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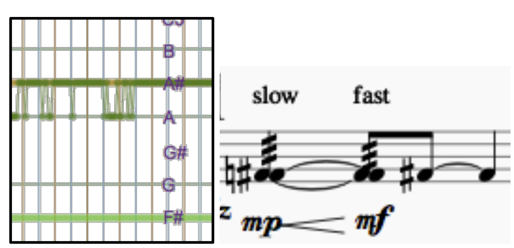

Figure 4.19: (a) Graphic representation of a highly fluctuating quartertone temperature change is represented in the score by a quartertone trill with volume swell markings below; (b) Semitone-based tremolos were constructed for the vibraphone and piano.

corresponding violin gesture while 4.19(b) depicts the graphed data and the resulting piano gestures.

According to Walker and Kramer, “it is important to know just how the manipulation of acoustic attributes such as the frequency or repetition rate affects a listener’s categorization of the sound.” [14] The passage of Much of the actual data in zones 3, 6 and 5 had been lost in the processes of rounding and transposing them into the vibraphone and violin pitch ranges. In addition, all scored material was non-repeating.

Because of these two factors, I felt that there needed to be some type of a clear, sonic reference for listeners to grab onto to help them apprehend the temperature changes occurring in the musification. Leaning back on my experience audifying the live compost soundscape in the *Sweeney Art Gallery*, I remembered and how the addition of directional, gamelan-based earcons helped listeners understand what was going on in the larger picture of temperature changes. In light of this, I decided to design a musical earcon to alert listeners of aggregate changes of ±1˚F in temperature. In addition, in order to orient the musification and listeners into the study’s temporal matrix, I also added a single ***f*** bass kick to signal the beginning of each day of the three-day study.

Figure 4.20 shows the two earcons I developed for *Sweeney Summer 2.* Earcon 1 signals an aggregate increase of 1˚F, while earcon 2 sounds when the temperature drops a full degree. Interiorly placed grace notes in each earcon indicate the newly reached temperature status. Accented ***sf*** dynamics placed on the octave-higher first 𝅘𝅥𝅯 note signals

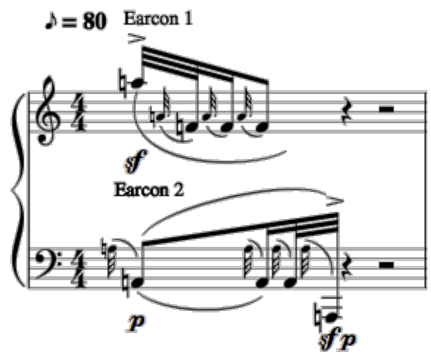

Figure 4.20: Designs for an upward indicating earcon (treble clef), and a downward indicating earcon (bottom clef).

a rise in temperature, while accented ***sfp*** dynamics placed on the last, octave-lower 𝅘𝅥𝅰 note of the beat indicates a full degree decrease in temperature. Intervals used for other repeated pitch material within each earcon varies contextually and depended more on my in-the-moment sonic aesthetics at the time of writing.

In an effort to draw even more attention to the earcons when sounded by an individual instrument, I also included echoing, reinforcing grace notes placed an octave

Figure 4.21: M. 2 of *Sweeney Summer 2*. Reinforcing grace notes played by the piano and violin align with the Earcons played by the vibraphone on beats three and six lend an overall structure to the work based on incidences of $\pm 1^\circ$ of temperature change.

higher than material being played in the other voices not initiating the earcon. All reinforcing grace notes are marked ***rfz*** in the score. Inclusion of earcon references unrelated to the temperature data in these voices also acts to give the performers sonic landmarks to work toward while navigating the otherwise irregular musical gestures. Figure 4.21 shows how the earcons and reinforcing gracenotes work in tandem to give the musification structure.

As a result, the sounding of the earcons becomes the only motif-based, repeating element in the work—giving it shape through repetition while building up listener expectation in an otherwise a-patterned dataset.

Returning to Walker and Kramer, “The extent to which listeners are able to learn the ‘language’ [of earcons] is also highly relevant”. [15] It is my hope to engage listeners in more than a ‘note-by-note’, in-the-moment experience of the piece—an otherwise abstract musification. In this spirit, the *Sweeney Summer 2* program notes explain the function and purpose of the earcons, how the passage of time is marked by the bass drum and invites the audience to listen actively for the changes.

CONCLUSION: *The Challenges Inherent in the Musification of Large Datasets*

Initially sonifying the 30-day sonification study in the digital realm allowed me to gain a deep understanding of the process of temperature change within the biota, closely mirror the dataset, and clearly delineate between the eight different temperature zones. While my earliest attempt in parameter mapping a much smaller dataset into a work for solo piano— *Desert Winter*—was quite successful in its portrayal of changes that occurred in the biota at the levels of pitch and rhythm, differentiation between zones using a solo instrument was impossible. Whereas data sonification's main goal is to effectively convey dataset-related aspects of the system being observed, portraying the datasets faithfully using acoustically-based instrumentation proved to be quite a challenge. In retrospect, I found that I had became quite attached to the high resolution of the data, and therefore felt that losing this feature when translating the data into the realm of acoustic instruments addressed my own creative agency as a 'sonification artist'. It was at this point in my research process that I became fully cognizant of the differences between data sonification and musification.

When moving from the precise, quasi-scientific realm of digitally-based data sonification into that of music composition for multiple human performers and acoustic instruments, my approach toward using data had to be transformed in some expected as well as unexpected ways. Hence, for *Sweeney Summer 2*—my second foray in data musification—I had no choice but to make a conscious break from such a literal reading of the dataset. The first challenge occurred immediately when I set about the task of rendering and translating the data from such a high resolution and rate of change into a form more executable for human performers. Interestingly, however, I found that striking a compromise between the very high resolution of data and a playable temporal resolution for human performers turned out to be an area where I had some of the most agency.

Humans, of course, are not machines, nor are acoustic musical instruments, thus my creative agency as composer was confronted in new ways. When a composer ties her ideas onto the ictus of a notated score, it is achieved through an intricate process of metaphor that relies on the basis of trust between her and the performer—therefore, the success of this new work hinged greatly upon developing the aspects of readability and performability in the data-based score for consumption and dissemination by professional musicians. Instead of a verbatim rendition of the data, as was possible using the audio display, it was necessary for me to rescale much of the data to fit into the ranges of the available instrumentation as well as reduce the resolution of the data to a more humanly playable scale. Through my experiences in distilling and developing the original, high-resolution dataset into *Sweeney Summer 2*, I came to realize that musification should be thought of as a more "humanized" form of data sonification. In the end, I made the realization that the success or failure of a data musification should not hinge on the basis of its being a note-to-note translation of datasets—as in digitally-based audification and sonification—but rather in its artistry in adapting a particular dataworld for successful embodiment by human performers, to be enjoyed, and hopefully also understood in some way by the audience.

I close this chapter on data musification, process and agency by bringing forward the words of online pioneer Ken Jordan:

> Digital media is opening new avenues to intimate personal expression—through the recombining of media elements, and the blurring of distinctions between traditional mediums in a way that reflects our intuitive engagement with the world. The line where art blurs into science is at the forefront of the discovery of new aesthetic experiences… the tools we have at our disposal to make art carry consequences for the art we make…the link between the notation on a page and the sound a musician makes when reading it is an interaction that blurs the line between mediums, just as digital media makes possible blurring in other ways… while the score provides an approximate transcription of a musical work, it is rough, open to interpretation… [16]

Sonification's capacity to synergize art, technology and data as a multimodal experience enables members of society to better perceive the world around them. My main contribution to the body of knowledge in the realm of data sonification art has been in sharing a deeply detailed, phenomenologically-based account of my direct engagement in all aspects of this project. The multifarious processes inherent in developing a project like *Composing [De]Composition* as sonification art have resulted in a rich entrainment practice in which my own creative agency blended with that of others—both human and non-human. Examination of the larger, techno-ecological processes that exist and supported the work—ranging from the biological aspects of compost and the composting process; designing and building the sensor apparatus; computer programming, sound and audio display design; to aestheticizing and re-aestheticizing compost for gallery and acoustic concert settings—has deepened my artistic and intellectual engagement with issues of environmental sustainability, process-based sound art, and the multivalent aspects of data sonification, just to name a few.

The advantages of participating in all of these processes has resulted in my deep, firsthand understanding the multifarious aspects of data sonification. Moreover, I made the full realization of its potential as an artistic medium for promoting exploration of our agential role in aspects of the everyday in order to illustrate larger, collective issues. As I anticipate a further broadening of my audience in transporting the work to future study sites and performance venues, I am inspired to continue to expand the project in many ways—but alas, this topic will become the subject of future papers. The main lesson learned from all these experiences however, is the importance of engaging my intended audiences—in the case of my adventures in digital data audification and sonification—the listener/visitor, and also the performers of it—in the case of data musification.

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1) Peter Sinclair. “Sonification: what where how why artistic practice relating sonification to environments” *AI & Society* 27 (2012), 175.
2) Ibid., 174.
3) Steve Reich, “Music as a Gradual Process” in *Writings about Music, 1965–2000*, ed. Paul Hillier (Oxford and New York: Oxford University Press,1968), 36.
4) Ibid.
5) Bruce Walker and Gregory Kramer. “Ecological Psychoacoustics and Auditory Displays: Hearing Grouping and Meaning Making,” in *Ecological psychoacoustics,* ed. J. G. Neuhoff (San Diego: Elsevier, 2004), 155.
6) Scot Gresham-Lancaster. “Relationships of Sonification Music and Sound Art”. *AI & Society* 27 (2012): 209.
7) Sinclair, “Sonification”, 175.
8) John Cage. *John Cage*, *Writer: Previously Uncollected Pieces,* ed. Richard Kostelanetz. (New York: Limelight Editions, 1993), 34.
9) Ibid., 111.
10) Ibid., 246-247.
11) Morton Feldman. *Give My Regards to Eighth Street,* ed. B.H. Friedman. (Cambridge: Exact Change Publishers, 2000), 136.
12) Feldman, *Give My Regards to Eighth Street,* 147.
13) Feldman, *Give My Regards to Eighth Street*, 6.
14) Bruce Walker and Gregory Kramer. “Ecological Psychoacoustics and Auditory Displays”, 156.
15) Ibid.
16) Ken Jordan. “Stop. Hey. What’s that Sound?” in *Sound Unbound*, ed. Paul Miller (Cambridge: The MIT Press, 2008), 250-251, 263.

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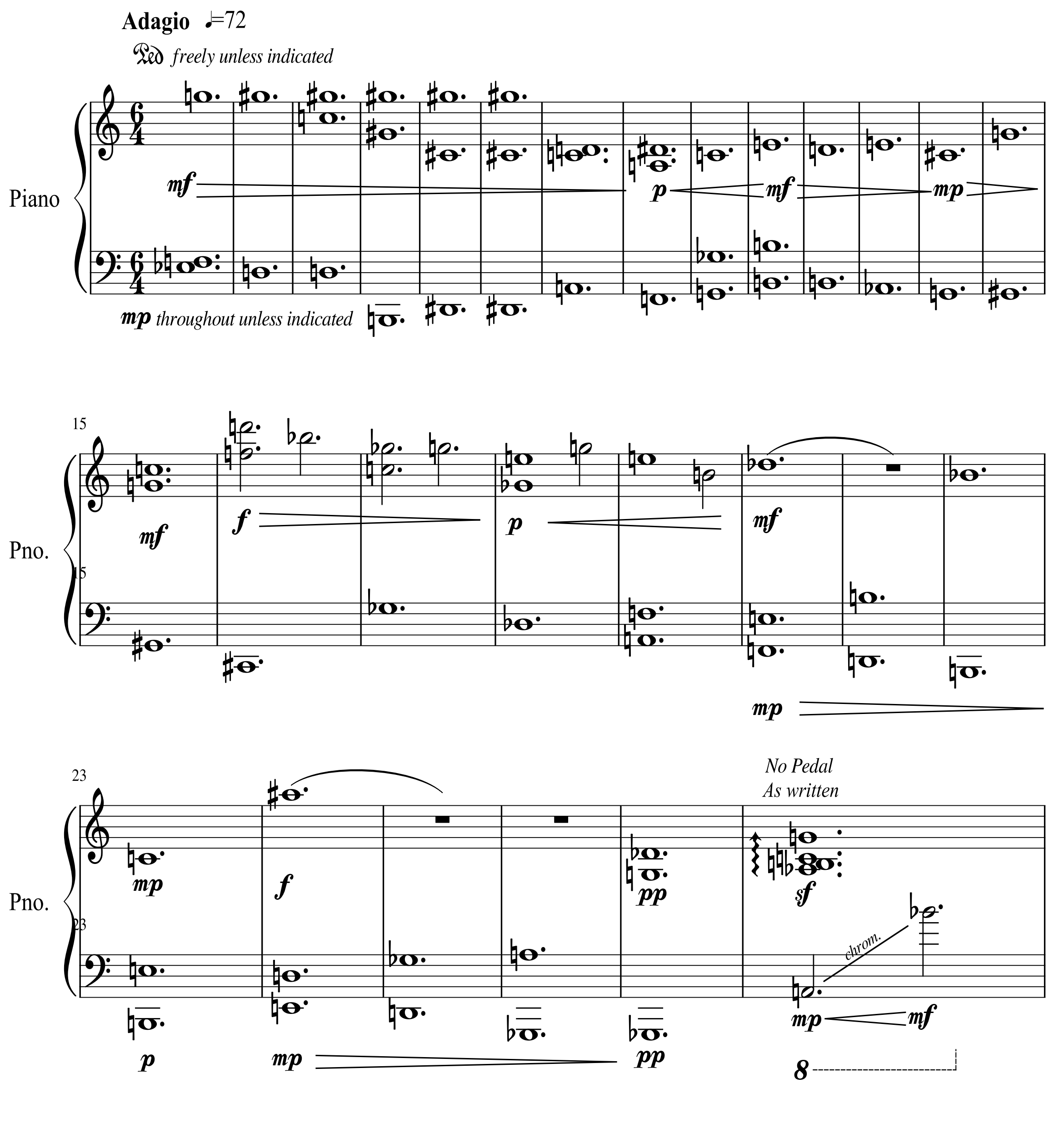
APPENDIX A: Data Musifications

Desert Winter

Riverside, December 2014-January 2015

J. no.e Parker



J. no.e Parker 2015


41
Pno.
43
8
Bass Clef as Written
45
As written
mp
49
sfp
mf
sf
mf
f


52
As written
Pno.
sf
f
mf
mp
56
Pno.
sf
mf
f
p
Ped

Sweeney Summer [2]

Riverside, July 25-28, 2015

J. no.e Parker


Vln.
Vib.
Pno.
Mallet
Change to Bow
Sustained, freely bowed
Earcon 1
mp
mf
rfz
sf
Change to Mallet
A
All Mallets
slow
fast


Vln.
Vib.
Kick
Pno.
Change to Bows
Sustained, Freely Bowed
Change to Mallets
Earcon 1
All Mallets
slow
fast
B
slow
slow

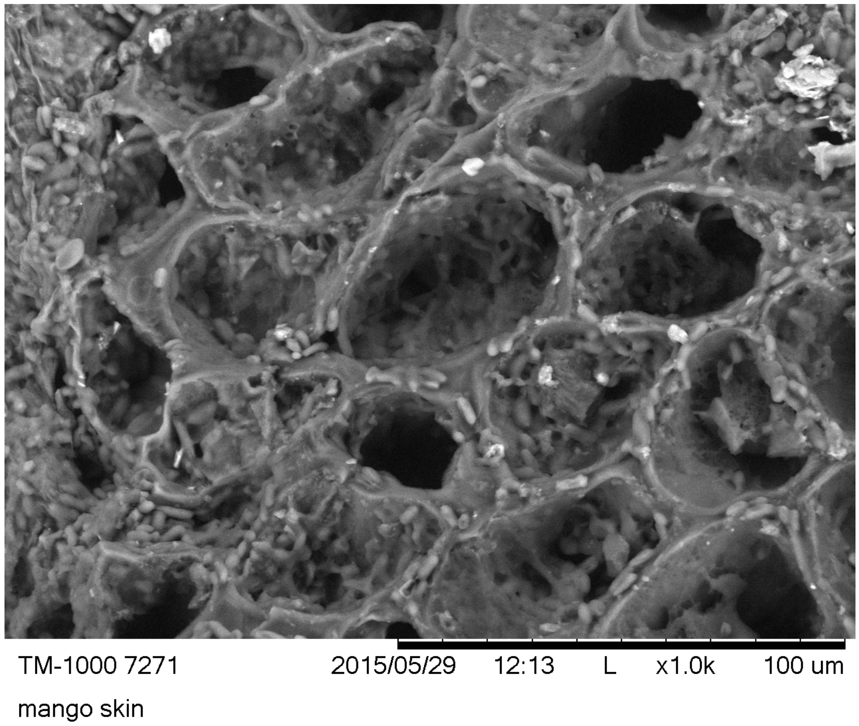
13
Vln.
rfz
dim.
Vib.
Change to Bows
All Bowed
mf
Earcon 1
Pno.
sf
ff
mf
14
Vln.
mp
tr
mf
Vib.
Change to Mallets
Pno.
15
Vln.
rfz
mp
tr
mf
Vib.
rfz
dim.
Earcon 2
Pno.
sf
mf
slow
C
16
Vln.
Earcon 1
sf
rfz
tr
mp
Vib.
rfz
mf
Earcon 1
sf
Pno.
rfz
Earcon 1
sf
ff
rfz


Earcon 1
Vln.
Vib.
Change to Bows
Sustained, Freely Bowed
Kick
Pno.
Change
to Mallets
Earcon 1
D
Earcon 2
Mallets
Slow
Earcon 1

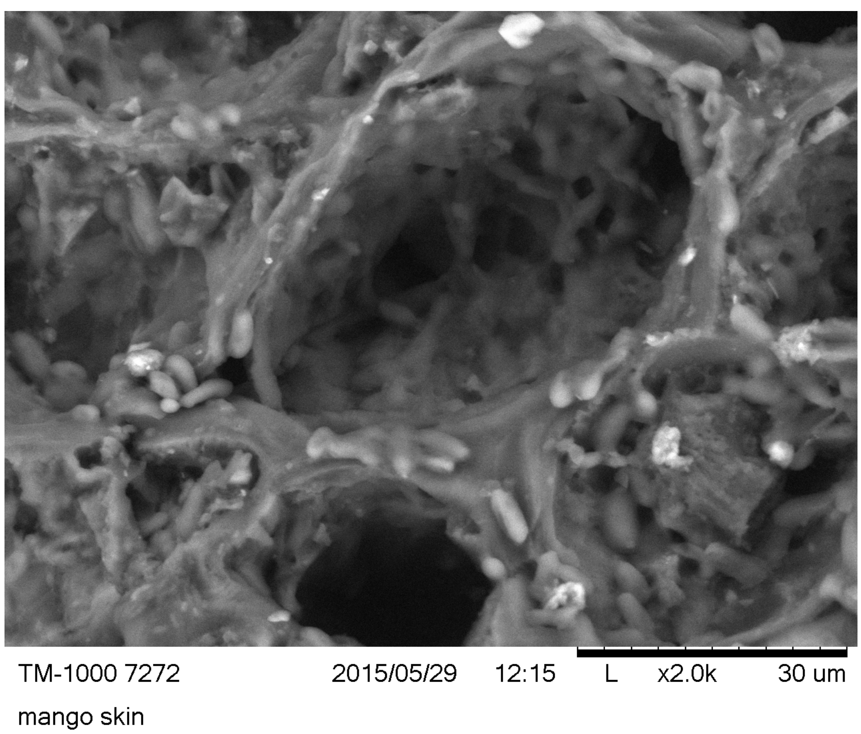

21
Vln.
mp
p
pp
Change to Bows
Sustained, F. Bowed
Vib.
f
p
fast
slow
Pno.
mp
p
22
Vln.
mp
rfz
mp
Change to Mallets
Earcon 2
Vib.
mp
p
sfp
Pno.
mp
rfz
mp


23
Vln.
Vib.
Kick
Pno.
Earcon 2
mp
rfz
mp
sfp
p
mf
D
24
callando
Earcon 2
gliss.
chrom.
ppp

APPENDIX B: Research Images

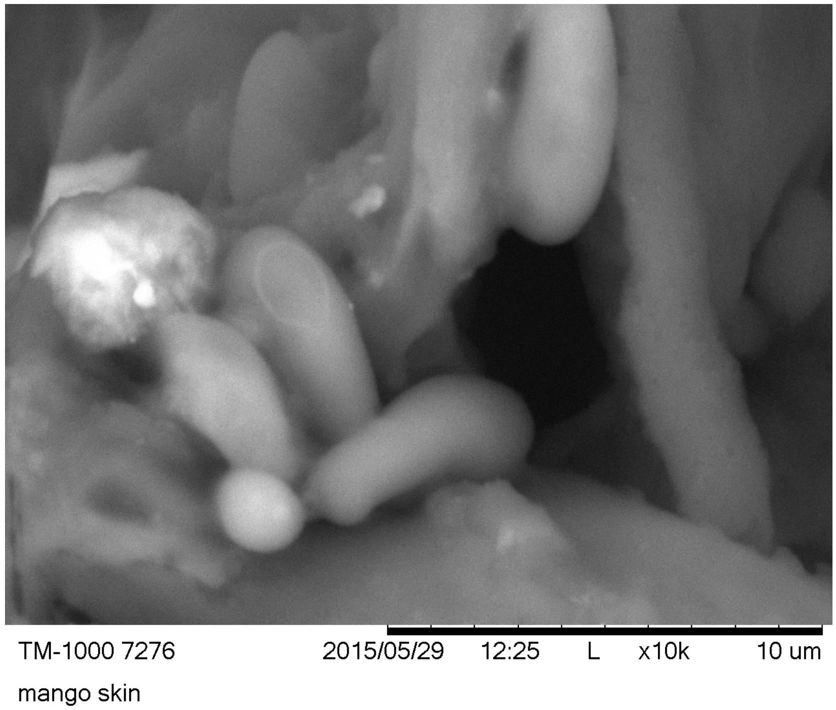


a.

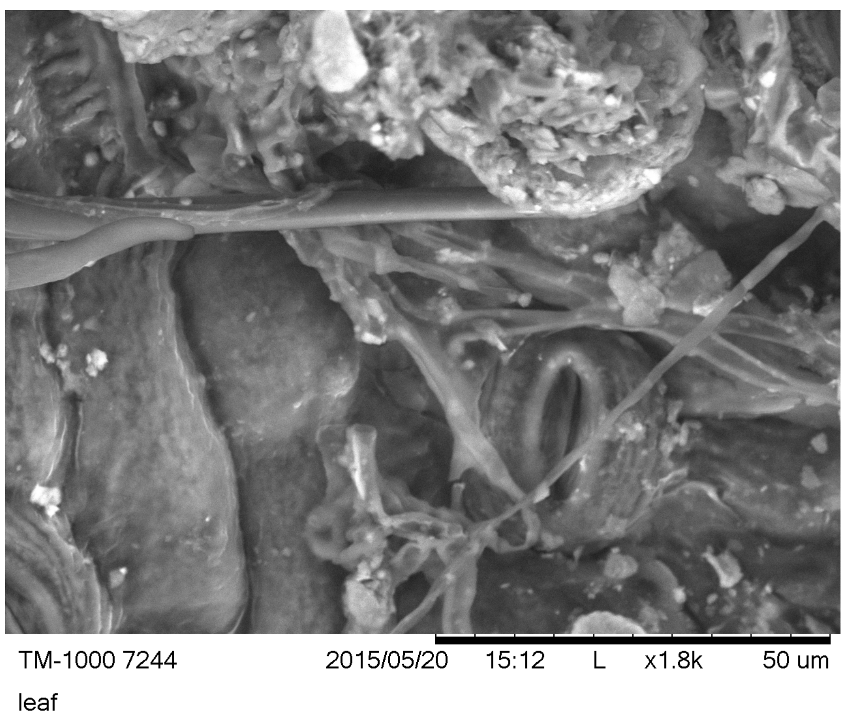


b.

Figure A.1: (a) 1000x scanning electron microscope magnification of a mango skin reveals tiny white, rod shaped bacteria; (b) the same area magnified 2000x.



a.



b.

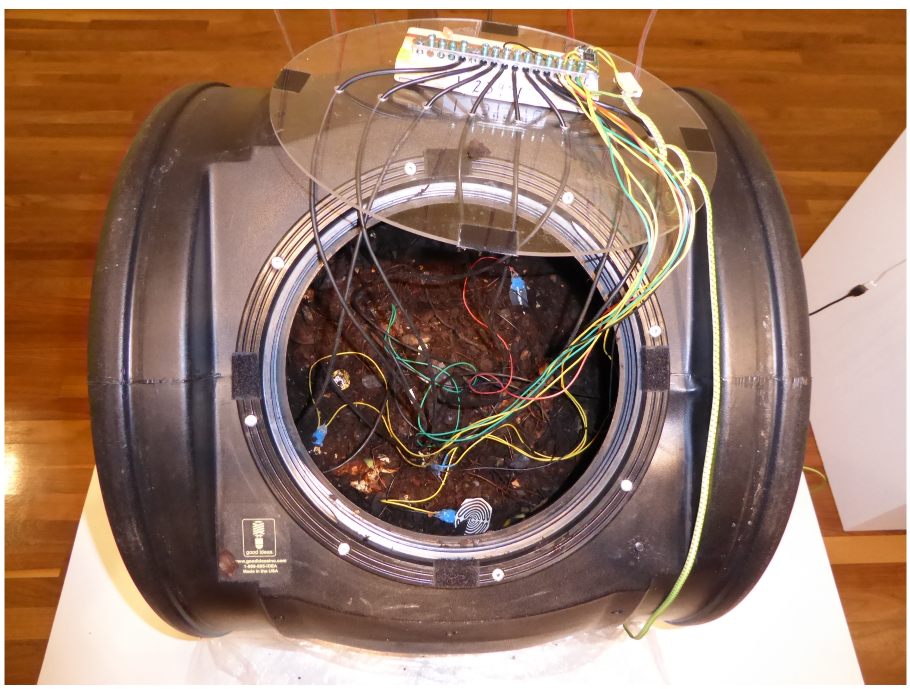
Figure A.2: (a) 10,000x magniication of a mango skin reveals a colony of rod-shaped bacteria; (b) the complex terrain of a leaf magnified 1,800x .

a.


b.

Figure A.3: (a) Close up view of *8 Jars* composting visualization at *Sweeney Art Gallery*; (b) the artist adds new material to the compost bin.

a.



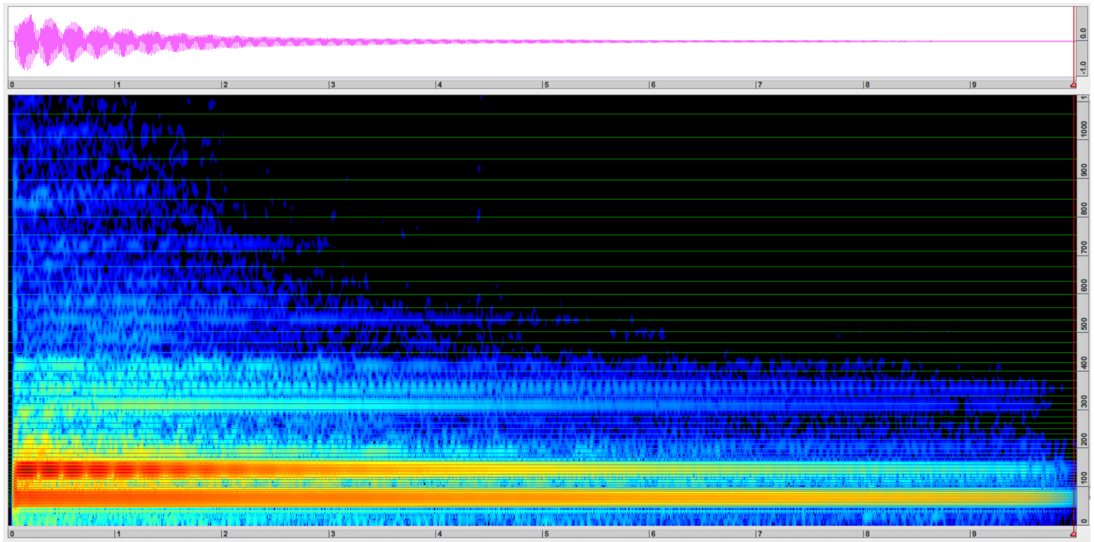
b.

Figure A.4: (a) Compost bin inside of the UCR Sweeney Art Gallery; (b) temperature sensing device with additional compostable paper sensors inside the compost container.

a.

b.

Figure A.5: (a) Gallery view of the BioArt lab at the UCR *Sweeney Art Gallery*; (b) the artist discussing the 30-day compost temperature dataset during a public event.

a. 

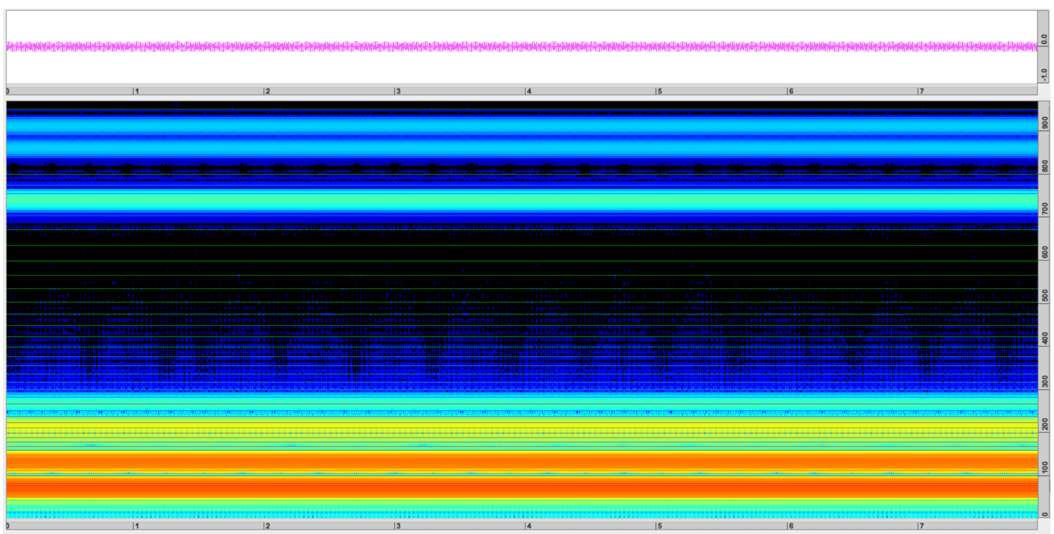
b. 

Figure A.6: (a) Gong sample used for Indoor compost temperature audification; (b) a single datapoint synthesized as the above gong sample.

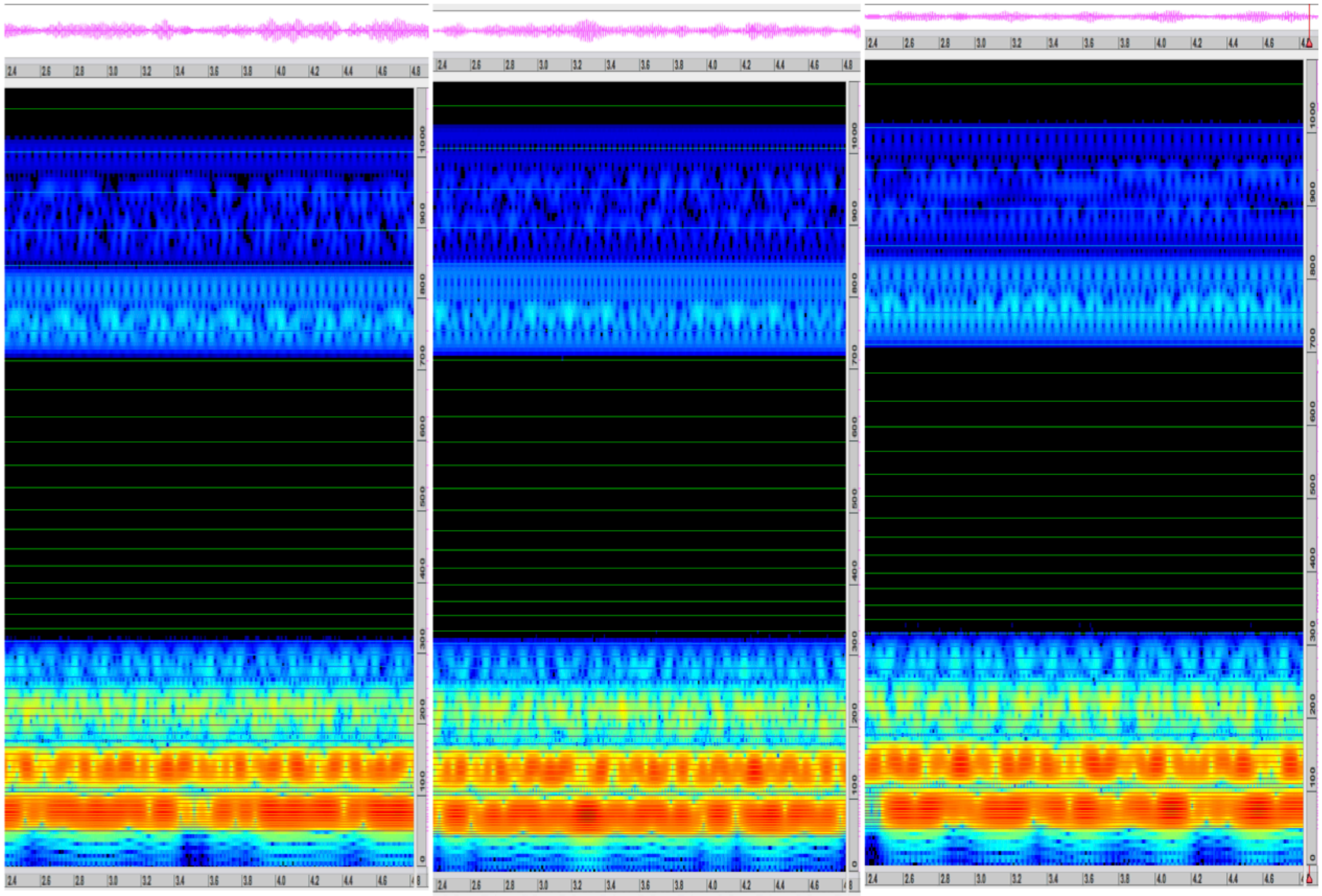


Figure A7: Enlarged view of a two second sample of the 8-point Hertz based sonification of data recorded on days 7, 8, 9 of the study visualizes the changing texutre of the gallery soundscape over time. Strong red areas below 100 Hz reflect the fundamental frequency and show convolution. Other colored materials above100 Hz threshold are resulting partials and also show convolution.