Music as an Act of Measuring Time and Space

By

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Figure 0.1: “one day” by Dave Scanlon
**Introduction**

I am currently in an eighteenth century New England home in central Massachusetts. The room I am sitting in has wooden floor boards and is painted an eggshell pink. The snow is rapidly melting outside due to two days of rain. There are a few things I can confidently say about the room; the room is a rectangle and the floor is uneven, the floor is slightly higher toward the door and it runs down to the windows. There are numerous movements that my eyes make in order to make these measurements. There is an imagined trajectory along one of the walls, and I imagine something moving from one corner to the other. This wall is one of the two long sides of the rectangle. I then imagine a movement across the short side of the rectangle. I confidently know that this distance is shorter. Then I imagine moving the short wall so that it is parallel with the longer wall. I fold the two walls so they lay against each other and I hypothesize that if the large wall is “1” then the short wall is \( \frac{2}{3} \). Then I decide to move across each length of the room and count my steps. The long side of the room is just shy of 22 steps while the short side is 16 steps exactly. My hypothesis was close though the long wall was slightly exaggerated in my imagined trajectory. I think to myself about Alvin Lucier’s *Vespers*, a piece where performers use echolocation to explore a room (Lucier, 87), and that my imagined trajectory is analogous to Lucier’s piece.

It is raining heavily and the sound is accented along one of the long walls because there is aluminum roofing just outside the wall’s windows. I sit and try to use
these accents to perceive the opposite wall. Since the sound is moving toward me from the wall closest to the aluminum roofing, I am unable to use it to directly measure the space between the accents and the opposite wall. The directness of the rain’s accents exaggerates the emptiness between the window and the opposite wall. If I stand next to the opposite wall and block the ear that is closest to the accented raindrops I indeed am able to hear the wall without touching it and therefore hear the space. I receive the accents from the opposite wall and they sound lower and muted as if a low pass filter and reverb had been placed on the sound. Certainly the room is a resonating chamber adding the reverb, and the reflection of the sound off the wall may have reduced the sounds high frequencies. The timbral shift in the sound is striking, and immediately I wonder how the previous action was a musical performance?

The room’s spatial proportions exist somewhere between ⅔ and ¾ giving the space the harmonic relationship of roughly a tritone. Through such performative measurement the room seems to loudly ring with a sustained resonance and I wonder whether the space was musical prior to my performance or whether I forced the music upon it? Maybe music can be simply a practice of investigation? Perhaps through a practice of measurement I was able to locate my body within its surroundings and feel the musicality of the space.

In Paul Lockhart’s book Measurement, he defines measurement as the practice of comparing one thing to another. It is a study of relationships. Musical and
mathematical practices both engage in acts of comparison. Listening to music asks the perceiver to perform relational comparisons of the perceived sounds. Such musical practices metaphorically overlap with geometric studies of physical properties such as length, mass, and volume. Within this thesis, I would like to explore music as an act of measuring time and space. This idea will be discussed through information theory and cognitive science. The overlap of these fields of research will be utilized in order to discuss Peter Garland’s *The Days Run Away*, Éliane Radigue’s *Phi 847*, and my own compositions; *Recounting* and *Reciprocal Harmony*. Information theory gives us insight into what a listener can perceive within an amount of time while cognitive science tells us how the perception may be processed. *The Days Run Away* and *Recounting* are both musical examples of temporal manipulation through repetition and low information density. *Phi 847* explores temporal stasis through a lack of discernible events. *Reciprocal Harmony* demonstrates the interconnection between physical space and intervallic space.

Information perception starts with a stimulus. The stimulus can be any type of information; for example, a sine wave oscillating at 440 hertz. Such a stimulus “in the environment emits energy that is absorbed by a sensory organ...causing sensation;” (“Sensation and Perception”) this process is known as transduction. The sensation is transmitted to the brain, which recreates the original sine wave as a “percept” (Nugent), or mental idea of the perceived sensation. If one has previous knowledge of a sine wave oscillator, then the sensation may be categorized as such.
However, if a listener does not have specific knowledge of waveforms, the sound may be categorized as a stable tone -- or perhaps the sound is heard as a tuning pitch, depending on the receiver’s background. Such categorizations involve comparing the stimulus to other familiar stimuli, registering its similarities and differences, and categorizing the stimulus appropriately (Barry). The process of recognition is inherently a process of comparison. If we continue with Lockhart’s definition of measurement, the practice of comparing one thing to another, then perception is an act of measurement. We measure the characteristics of a stimulus against other previously encountered stimuli. This process of measuring is constantly at play when we perceive music. We measure the sounds in relationship to what we have previously heard or of which we have knowledge.

The physical properties of sound suggest that these measurements are both temporal and spatial, the oscillation of a sound wave between negative and positive is a change in position over a period of time. It is the intersection of time and space. Though music may be received in infinite registries, this movement, change in position over a period of time (Lockhart, 201), is essential to sounds’ physicality. A listener’s perception of this physicality depends on a myriad of contextual factors. Though the perception is subjective the act of measurement may be consistent.

The temporal aspects of music exist on multiple levels. First, a musical piece unfolds over time and, secondly, its reception is tied to one’s ability to process that material within an amount of time (ie, the amount of time it takes one’s perceptive
functions to execute). As Brün posits, the temporal aspect of music is communicated through the perception of noticeable separate events (Brün, 10). The spatial aspects of music relate to sounds’ movement -- its movement through space. To perceive sound is to perceive a space. Though music may be received in infinite registries, this movement, the change in position over a period of time, is essential to sounds’ physicality.

This understanding of music’s temporal and spatial characteristics allows me to make two suggestions. First, if the perception of our bodies in a space is essential to music then an act such as the aforementioned measuring of the bedroom is musical. Second, if music can be viewed as a measurement of time and space and then from that starting point we are able to remove sound, potentially with the removal of sound’s physicality our conception of music could be reduced to a measurement of time without space.
**Kappa and Tau Effect**

Through research exploring the theory of relativity, physicists view the measurement of time and the measurement of space as interconnected actions (Mackenzie, 1). Within Noah Mackenzie’s *The Kappa Effect in Pitch/Time Context*, the aural implications of psychological relativity are explored in order to demonstrate the interconnection between the perception of pitch and time. The theory of relativity in physics demonstrates that “space and time are... mainly seen as inseparable aspects of one underlying dimension, space-time... There is a small but significant body of research suggesting that something akin to psychological relativity exists. Psychological relativity can be thought of as the effect of space on temporal perception (or conversely, the effect of time on spatial perception)” (Mackenzie 2).

The kappa effect, “the effect of spatial extent on the perception of time” (Mackenzie, 2), is demonstrated to be a realization of psychological relativity.

Italian psychologist Vittorio Benussi was the first to demonstrate psychological relativity in 1913 with an experiment where viewers saw “three successive flashes of light that defined two spatial distances” and two temporal distances (Mackenzie, 2). Though the exact details of the experiment are debated, we know that three lights were flashed in succession and that the second flash varied in both its temporal and spatial placement (*Space and Time in Benussi Tau Effect*). The study found that one’s spatial judgment is dependent on the temporal variable. American psychologist Harry Helson altered this study in 1931 to test tactile
perception by touching three successive points on the subject’s skin: if the time it took to get from point A to point B was longer than the time it took to get from point B to point C then the subject reliably said that point A and point B were spatially farther apart even if they were actually closer (Mackenzie, 2)(Birgitta, Benoît, 2). Again, the spatial perception was found to be dependent on the temporal variable. The longer length of time caused the subject to perceive the distance as larger. Helson called this phenomenon the **tau effect**. The tau effect is the inverse of the **kappa effect**. The *tau effect* suggests that the temporal quality affects the perception of space, whereas the *kappa effect* posits that the spatial quality affects the perception of time (Birgitta, Benoît, 2).

Though not the first to study the *tau/kappa effects* within an auditory context, Japanese psychologist Sumi Shigeno was able to provide substantial proof for the interdependence of space and time in auditory perception (Mackenzie, 5). Shigeno played subjects three successive sounds, A - X - B. A was always 1000 Hz while B was always 2500 Hz. A and B were separated by one second of time. X could be 1000, 1350, 1750, 2150, or 2500 Hz and could be placed .41, .44, .47, .50, .53, .56, or .59 seconds after sound A (Mackenzie, 5). Shigeno found that if X was closer to A in frequency then subjects reported that X was closer to A in time even if the opposite was true. If X was closer to A in time, subjects judged it to be closer to A in frequency even if the opposite was true.
Collectively, these studies show that temporal perception is integral to spatial perception. Mackenzie’s additional studies support a theory of Modified Auditory Motion, which suggests that we perceive space and time as related to movement (Mackenzie, 112). For example, when one hears three successive sounds in three different locations, it is imagined to be one sound moving from one place to another. In this example, there is an imagined trajectory of an imagined object, taking a longer time to move a further distance. Movement is also how we perceive frequency distance. We imagine one object traveling at a consistent speed from one frequency location to another. However, Mackenzie’s studies found that if a sound contains many large intervallic leaps the listener no longer hears the sound as one object moving to different locations but instead different sounds turning on and off (Mackenzie, 112). With these findings, listening to music involves making sense of a simultaneity of interrelated measurements that are aided by imagined movement.

The kappa/tau effects demonstrate that space and time are not separable dimensions in the auditory realm and Mackenzie’s studies show that the connection of space and time is processed or understood as movement. Given these ideas, we might hypothesize that stillness or extremely large intervals may distort our perception of these dimensions. By reducing the movement or surpassing what could be an imagined trajectory a listener may be aurally manipulated.

Looking to explore and extrapolate the idea of Modified Auditory Motion, I stood in front of a stereo with my computer running through its speakers. The
computer randomly chose two tones between 60 and 4,000 Hertz.¹ I removed my watch and listened to the sound. One of the sounds seemed to be in the 700-1000 Hz range while the other was certainly above 2,000, perhaps just under 3,000. I perceived a “distance” between the two sounds; I heard them as separate sounds, wider than the critical band, and I focused on each of them separately in order to explore the sound.

Like the imagined trajectory I completed while measuring the bedroom, I imagined moving from one intervallic location to the other, however the tones are not moving objects. The sound’s stasis forced me to stay still and at times allow my attention to move from one intervallic location to the other. Stasis and its suggestion of infinity (that these sounds might continue on, unchanging) caused the time to simultaneously have no motion and leap forward. My method of measuring the sounds’ intervallic distance ignored potential relational distance such as a perfect fifth or octave by focusing on frequency. If the two random tones by chance ended up being an octave or a perfect fifth, my method of imagining an object moving between the two frequency locations would have ignored the relational closeness. The relational closeness stems from the sounds’ intervallic ratio, resulting in the ratios’ consonance. Potentially, the sounds would have been heard as closer together due to their relational closeness, even though they may be far apart in regards to their Hertz value, reversing the findings of the kappa effect. The two tones previously played by

¹ I ran these experiments in SuperCollider using the following code: `{LFTri.ar([rrand(60, 4000), rrand(60, 4000)], mul: 0.5)}.${play};
the computer are not heard as consonant. They are not heard as any of the regularly occurring intervals, and it can be assumed that the their intervallic ratio is rather uneven. Though some of the studies exploring the \textit{kappa/tau effects} have used equal-tempered pitches, I have not found supporting scientific evidence at this time that greater consonance (relational closeness) brings sounds temporally closer together.

After an unknown amount of time, I changed the computer to instead play a stream of individual, randomly chosen frequencies within the range of a major third. The computer randomly chose the speed at which the frequencies were played, between a range of 0.2 seconds and 0.35 seconds.\footnote{The following code was used in SuperCollider 3.7.2 to execute this experiment:}

\begin{verbatim}
(SynthDef('tri, { | out, freq = 500, amp = 0.4, suslevel = 0.9, releasetime = 0.01, pan = 0, gate = 1 |
    var audio, env;
    env = Linen.kr(gate, 0.001, suslevel, releasetime, doneAction: 2);
    audio = LFTri.ar(freq, mul: amp);
    Out.ar(out, Pan2.ar(audio, pan, env));
}).add();
(~trajectory = Pdef('trajectory, Pbind(
    \instrument, "tri",
    \freq, Pwhite(500, 625),
    \dur, Pwhite(0.2, 0.35),
    \legato, 0.7,
    \amp, 0.6
));)
~trajectory.play;
\end{verbatim}

This monophonic melody sounded like one object propelling itself forward. The narrow frequency range allowed the sound to be heard as one object moving between different intervallic locations, demonstrating the \textit{modified auditory motion} phenomenon. Within the range...
of a major third, the intervals on the larger end of what is intervallically possible were
temporally exaggerated due to the *kappa effect*. The *kappa effect* within the context of
the randomized monophonic melody caused intervallic space to be perceived as a
physical space that one imagined object moved through. This experiment
demonstrated the insight drawn from experiments regarding the *kappa effect*: the
perception of physical space and intervallic space function similarly and are related to
the perception of time. Intervallic harmony is created through differences in
frequency. Since all sounds travel at the same speed, the variable for creating
harmony is the distance a sound wave needs to travel in order to complete one
oscillation. This distance is a physical distance. As a result, when a listener perceives
intervallic space they are perceiving physical space and these perceptions are tied to
time.
Measuring Time and Altering Temporal Perception

In *The Function of Time in Art*, Herbert Brün (1962) creates a framework for discussing the subjective perception of time. He argues that the passing of time is perceived by noticing events, which he defines as any noticeable change (Brün, 10). Within this framework there are two possible ways of changing the listener’s perception of time: the first is to change the quantity of events within a specific amount of time. The second is to change the amount of time it takes to execute a quantity of events (Brün, 12). For example, if two different quarter notes are played in the time of two seconds and then six different triplet eighth notes are played in the time of two seconds, the events have become faster. However, if three quarter notes are played in the time of three seconds and then the same three quarter notes are played in time of ten seconds, the time got slower, not the events. These two ways of changing the listener’s perception of time are notated below:

*Figure 3.1: events become faster*
Brün’s compositions, such as *Five Pieces for Piano, Op. 1* (1940-1945), reflect this shifting in the rate of events and the underlying tempo. When there are no discernible separate events, the sonic texture is heard as a single event. Textures that change continuously and textures that change in such subtle ways that their transformation is unnoticed are both perceived as single events (Brün, 11). If discernable events are the gauge for the perceived passage of time, then I would suggest following equation for measuring the perceived rate of time:

\[
\text{rate of time passing} = \frac{\text{discernable events}}{\text{well-defined unit of time}}
\]

This formula is helpful and accurate to a certain extent; however, there is a “ceiling” to the quantity of events one may perceive within a given amount of time. A rhythmic pulse increasing into audio rate and becoming a single tone can be seen as a metaphor for the quantity of events increasing until they are perceived as a single event.

“Quantity” isn’t the only characteristic that affects how events are temporally perceived; an event’s “information density” must also be considered. Information
density is the amount of information within each individual event, where information is defined by how likely the event is to happen. These idea of information density was developed and explored in depth within the field of Information Theory. In order to determine an event’s information density, one must determine the likelihood of its occurrence. Information Theory determines an event’s “likelihood” by measuring the amount of uncertainty within a “well-defined universe” (Feldman et al, 184). In order to construct a well-defined universe, one must first “associate with this universe a finite number of distinguishable states which are, also, all the states that the universe can assume... [for example] a die with its six faces, or a coin with its two sides, may be considered as such a universe. The face or the side that comes up after the die or coin is tossed, represents a distinguishable state in these respective “universes”” (Feldman et al, 184). Once the different states within a universe are defined, it is possible to calculate the probability of a state’s occurrence. That probability (how likely or unlikely the event is to occur) determines the quantity of information that each distinguishable state contains. Utilizing music theorist David Temperley’s research, “An element with a probability of 1 is completely predictable and thus carries no information; as elements decrease in probability, they become more surprising and hence more informative. Something with a probability of zero is completely surprising and thus conveys infinite information... Given a series of elements presented over time, we can define the information density (or information flow) as the amount of information per unit of time. Psycholinguistic studies have
shown that low-probability elements (e.g., rare or unexpected words) take longer to process (Levy); this suggests that there is an upper limit to the level of information density that human perceivers can easily absorb. But it is also, presumably, desirable for information flow to be fairly close to that limit, so as to maximize the amount of information conveyed” (Temperley, 156-157).

An example to illustrate this principle is a tonal piece of music played on a diatonic harmonica. In this case, all the notes of the C-major scale would be distinguishable states. If the piece of music is in the key of C-major, the likelihood of a C’s occurrence would be different from the likelihood of an F’s occurrence; this is both a result of C being the tonic and it physically occurring four different times on the harmonica where the F occurs only twice on the harmonica. In this example, F is a high information density occurrence because it is less likely to occur, given the possibilities of the “well-defined universe” of the diatonic harmonica.

Since the communication of information is tied to the rate of delivery, then the perception of time may be altered by a) the rate at which information is delivered and, as explained in the theory above, b) the probability of the information. Previously, when two random tones were sustained by my computer there was infinite time for processing the initially surprising information. This pacing was far below the usual rate of communication, therefore my perception of time passing dramatically slowed. When the computer was generating a monophonic melody between the range of a major third at a rate ranging from 0.2 to 0.35 notes per second, my perception of time
passing greatly increased as I followed the imagined trajectory of the melody that randomly raced ahead. Each frequency in the monophonic melody was chosen randomly, therefore it was always surprising in some way. My cognitive processing of this information needed to keep pace with the rate at which the frequencies were being chosen, between 0.2 and 0.35 notes per second. Either as a result of the melody’s randomness, or through my own conscious effort, I perceived each frequency as a discernible event. Within the context of these two examples, the perceived rate of time passing equalled the amount of discernable events divided by a well-defined unit of time (in this case, clock time):

\[
\text{perceived rate of time passing} = \frac{\text{discernable events}}{\text{a well-defined unit of time}}
\]

This equation functions until what Temperley calls the “upper limit” of what one is able to perceive within a given amount of time. When the limit is reached, the separate events are perceived as a single event and the discernible events value within the equation should return to one.

Temperley utilizes Information Theory to explain why highly chromatic or intervallic themes are repeated. Chromatic themes and successive large intervallic leaps have a low probability, making them information dense. Information dense sounds take a longer time to process, therefore repetition may be used as a processing aid. Through exact repetition, a phrase moves from low probability to high probability. The content that is heard as a discernible event in its original statement...
moves forward in two temporal registers: each exact repetition as a micro event of completely probable information and all the repetitions psychologically grouped together into one macro event. If no new information is presented within the repetitions, temporal perception slows down. In Peter Garland’s *The Days Run Away*, repetition and high-probability information are used to slow the perceived rate of time passing; this and other characteristics of the piece are explored in the section below.
Peter Garland’s *The Days Run Away*

Peter Garland’s *The Days Run Away* (1971) is a piano piece made up of eight different repeated module cells. The performance notes indicate the form and its overall quality:

“There are eight segments in the piece (plus #1 twice). They are to be played through in order, 1-8 -- at a slow, dreamy pace that will emphasize the gradual transformation that the original phrase undergoes. Pedaling is free, and the rhythm need not be completely strict. Once through #8, the player should retrace his or her steps back to #1. A suggested order would be 1-8, 4, 3, 2, 1; but the performer may make that decision. The reprise perhaps should be taken more quickly than the original statement. Average performing time is 20 minutes, and the dynamic level throughout is piano” (Garland).

In this analysis, I assume the performer follows the suggested structure for the ease of discussion. In this case, there are a total of twelve segments played over the course of twenty minutes. From the composer’s instructions, this pacing seems to have the optimal combination of information and duration in order to achieve the sought-after “slow, dreamy pace”. Using the previous equation, this pacing could be expressed as:

\[ \text{rate of time passing} = \frac{12 \text{ discernable events}}{20 \text{ minutes}}. \]
As a result, each segment should be played for an average of one minute and forty seconds. Following this pattern, the reprise will take half the length of the original 1-8 segments: the entire piece ideally is 1200 seconds, each segment is 100 seconds, and 1/12 of the entire piece. The original 1-8 segments will be 2/3 the totality, while the retake is 1/3. The music floats through an E natural minor/E Dorian/G Lydian/G major tonal space. The harmony sustains an effervescent quality. None of the chords or their progressions give an impression of tonic or dominant relationships. During the first 5/12 of the piece, only one note is added with each new segment. All of the information that occurs, meaning the succession of notes, is of a high-probability.

![Figure 4.1: segment 4 notated](image)

In segment 4 (fig. 4.1), the piece moves from E natural minor to E Dorian with the addition of the C# and removal of the C natural. Despite this change, the piece has an overall diatonic feeling. Throughout the first 1/3 of the piece one diatonic note is added per segment. These additions are largely low information/high-probability messages. The second 1/3 features between 3-4 changes per segment. The last 1/3 is a recapitulation.
When discussing recapitulation in his own work, Herbert Brün writes, “this return to old things, this recapitulation, was designed because I wanted the listener to gain the impression at the end that no time at all had passed, as if everything was nothing but a dream” (Brün, 33). This idea — that a recapitulation is a suggestion that time has not passed -- works in conjunction with the idea that the perceived rate of time passing is a result of noticing discernible events. In the case of The Days Run Away, where the recapitulation returns the listener to the beginning and does so through a slow, gradual process, then there may be a suggestion that time had not passed. However, as the title reminds the listener, the days run away -- time slips away from us. Time may run away, but through the repetition of memories one can suggest the repetition of an earlier time.

Exact repetition is both predictable and unsurprising. An exact repetition has a history because it was heard before and suggests a future with the high probability of an additional repetition. Having heard the sounds before, a listener can imagine them happening again. The exact repetition used in The Days Run Away suggests endlessness. The segments have a history and a future. The segments change in subtle ways by having each additional piece of information be of high-probability, resulting in a texture of near eventlessness.

Through the composition’s form there is an effort to slow down the listener’s perception of time, to literally let the days run away. Sustained, consistently high-probability information delivered in a slow, even manner asks very little of the
interpretation portion of the listener’s consciousness. In the psycholinguistic sense, the listener is far from that upper limit of the information density they are capable of receiving. Music theorist Jonathan D. Kramer refers to such temporal qualities as “vertical time,” a “temporal continuum of the unchanging, in which there are no separate events and in which everything seems part of an eternal present” (Kramer, 454, cited in Bellouin). Through the melding of events, the listener’s temporal perception may be paused or manipulated.

In the instructions for The Days Run Away, Garland asks the performer to give the piece a “dreamy” quality. In dreams, one isn’t tied to a world of mathematical logic. Time is able to be even more amorphous. The sense of vertical time that is achieved in The Days Run Away points toward a dreamlike state where an “eternal present” may be possible. The repetition and the slow presentation of high-probability information add to the dreaminess by communicating information at a much slower rate than what one usually encounters in general conversation. It is far from the upper limit discussed in psycholinguistics. Garland’s insistence on freedom in the piece’s instructions and his inclusive stance toward the performer (the pedaling is free, the rhythm is not strict, and the form is left open to the performer’s interpretation) points toward imagining a dreamlike place of malleable physical properties.

In regards to the kappa/tau effects, it is difficult know in what ways this phenomenon is playing out on a micro-level. Depending on the performer’s chosen slowness, the tempo might allow for modified auditory motion, perceiving a melody
as one imagined object moving between different intervallic locations. The *kappa* and *tau effects* demonstrate to us that our perception of time and our perception of space are dependent on one another. As a result, the temporal unfolding of *The Days Run Away* will have an impact on both the way the listener perceives the music’s intervallic space, as well as the space in which they occupy. What I still wonder is if the relational closeness of the diatonic harmonic material has the ability to bring the content temporally closer together?

The *kappa effect* demonstrates that a larger frequency distance pushes sounds temporally further apart and a smaller frequency distance pulls sounds temporally closer together. Is there any way, particularly within a diatonic texture, that material is brought temporally closer together simply by the relational closeness of the intervallic material? If so, then a piece of music that is similar to *The Days Run Away* but exclusively uses atonal material may also slow the listener’s perception. This idea directly opposes the idea of presenting information that is exclusively high-probability in order to bring the content far below a receiver’s upper limit, and therefore slow the perception of time. Time-perceiving aparati and processes are multi-faceted, synthesizing multiple phenomena. Such relational closeness relates to what French composer Éliane Radigue describes as the “*distance between proximity and familiarity*” (Radigue, CD liner, ORAL). Relational closeness, which I use to describe consonant intervals in the case of Garland, suggests familiarity through the intervals’ common occurrence and the simplicity of their intervallic ratio. In the case
of Radigue’s work, familiarity is utilized through sonic stasis, sonic material returning after an extended duration, and consonant intervals separated by many octaves. These concepts will be explored in the context of her piece *Phi 847* in the following section.
Éliane Radigue’s *Phi 847*

The sounds used in Éliane Radigue’s *Phi 847* (1972) were created on an ARP 2500, recorded onto magnetic tape, and then arranged into a final mix. Radigue’s compositional practice can be seen as a form of musical measurement.

*Quivering, murmur of sound material.*

*Slow stretching. Time suspended within the time unit.*

*Feline softness masking capricious savagery.*

*Impossible taming.*

*Distances between proximity and familiarity.*

1. *Primary material*
2. *First elaboration*
3. *Conflict*
4. *Resolution*

-Eliane Radigue, CD liner notes ORAL 57

Formally *Phi 847* has four distinct sections that dovetail or blend into each other. I identify these four sections as follows:

<table>
<thead>
<tr>
<th>Section</th>
<th>Time</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Primary material)</td>
<td>0:00-17:00</td>
<td>seven groupings of tones neatly dividing 0-16,000 Hertz</td>
</tr>
<tr>
<td>II (First elaboration)</td>
<td>17:00-42:00</td>
<td>Sparse with gong-like rhythmic pulse and nothing above 700 Hertz</td>
</tr>
<tr>
<td>III (Conflict)</td>
<td>42:00-52:30</td>
<td>descending melody with sustained tones dividing 0-16,000 Hertz</td>
</tr>
<tr>
<td>IV (Resolution)</td>
<td>52:30-1:11:00</td>
<td>dense full spectrum sound without rhythmic pulse</td>
</tr>
</tbody>
</table>

*Figure 5.1: section descriptions*
Section I can be described by its seven groupings of sounds cleanly dividing the range of human hearing. Some of these sounds are individual frequencies while others exist as tightly woven collections. I describe these in the following table:

<table>
<thead>
<tr>
<th>Section</th>
<th>Frequency Range</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>0-400 Hertz</td>
<td>Collection of sounds between 0-400 hertz with a modulating quality; potentially containing some AM synthesis; some of the sounds in this range maybe incidental noise created by the synthesizer, such as 60 Hertz amp buzz.</td>
</tr>
<tr>
<td>Group II</td>
<td>400-600 Hertz</td>
<td>Collection of sustained midrange tones featuring numerous beat frequencies</td>
</tr>
<tr>
<td>Group III</td>
<td>600-800 Hertz</td>
<td>Consistent pulse similar to a percussively triggered resonant filter</td>
</tr>
<tr>
<td>Group IV</td>
<td>800-1200 Hertz</td>
<td>Constant sustained tone at 1000 Hertz; evenly spaced “half notes” at 800 and 1200 that are potentially difference tones resulting from the upper register material</td>
</tr>
<tr>
<td>Group V</td>
<td>3500-5000 Hertz</td>
<td>One sustained frequency at roughly 3500 Hertz, a second sustained frequency at roughly 4000 Hertz, and a pattern of “half” notes alternating between 3500 Hertz and 4900 Hertz.</td>
</tr>
<tr>
<td>Group VI</td>
<td>7100 Hertz</td>
<td>Sustained frequency at 7100 Hertz</td>
</tr>
<tr>
<td>Group VII</td>
<td>16000 Hertz</td>
<td>Sustained frequency at 16000 Hertz</td>
</tr>
</tbody>
</table>

*Figure 5.2: group descriptions*

For each section of the piece, I will present a spectral analysis image of the section made using the Adobe Audition software, followed by a written analysis.
In relationship to the kappa effect, the large distances separating these sounds (visible in the spectral analysis above) allows for each one to be perceived individually. Research by psychologist Noah Mackenzie in *THE KAPPA EFFECT IN PITCH/TIME CONTEXT* suggests that if the intervals are large enough, the phenomenon of *modified auditory motion* will not function. *Modified auditory motion* is the idea that successive sounds may be heard as one imagined object traveling to different intervalllic locations (Mackenzie, 112). If the intervalllic content is large enough, the different sounds are perceived as different objects turning on and off. As a result of the large intervalllic distances in Section I, the sounds are not heard as one chord made up of many tones but instead different juxtaposed sounds turning on and off. There is no imagined object moving from one intervalllic space to another; instead, there are separate individual sounds, the distance between which the listener can imagine traversing. The listener is able to use these sounds to departmentalize each section of their own hearing range. Such division and juxtaposition requires
measuring each individual sound against the other as the listener attempts to locate the individual sounds in intervallic space.

When presented visually, the spectrum of sounds in Section II appears as follows:

![Spectrum of sounds in Section II, 17:00-42:00](image)

*Figure 5.4: Section II, 17:00-42:00*

Section II is both the longest section, at 25 minutes, and also the most sparse. Within this section, the listener hears a sustained drone with subtle modulation creating beat frequencies in the texture’s amplitude and an unstable pitch. There is also a repetitive, bell-like sound that resembles a resonant filter with a percussive envelope being struck by trigger voltage. The drone and bell sounds have roughly the same frequency until 30:30, when the frequency of both begins to shift as Section II gradually transitions into Section III. Throughout Section II the matching frequencies give the effect of the sustained drone suddenly becoming percussive. This matching is emphasized through mixing techniques such as amplitude levels and placement within a stereo field. In Radigue’s remarks about the piece she refers to a “slow
stretching,” and her approach to mixing exaggerates this idea. Each entrance of new material is gradually faded into the mix, or vice versa as each sound is gradually faded out. With fades taking upwards of 12 minutes each, and each fade being staggered, these entrances and exits are not perceived as fades but rather as transformations.

Dividing Phi 847 into sections is seemingly wrongheaded and is impossible to do without listening multiple times and examining a spectral diagram. Instead, the piece is perceived as one section that is constantly presenting new information at a glacial pace. The fades are so gradual that it gives the impression of material being stretched or rather expanded. Specifically, in Section II, the bell sound fades in after the sustained drone has been established. The two elements’ matching frequencies give the impression of the sustained drone slowly becoming pulsed. In reference to such textures Brün writes, “if one cannot discern such moments [separate events], one prefers to follow the whole continuous process as a single event, calling it a movement. Movements are events in that they have a noticeable beginning and a noticeable end. Most movements seem to be eventful events as they seem to be full of changes. But the exact points and duration of these changes evade the searching eye and ear” (Brün, 11). The entirety of Phi 847 may be heard without separate events and the seventy-one minute movement experienced as a suspension of time.

The spectral analysis of Section III appears below:
This section acts as an extended transition between Section II and Section IV. The sustained, mid-range drone remains the same between Section II and III, while the frequency of the bell sound shifts in order to play a descending melodic passage which repeats throughout the section. Additionally, sustained pitches enter separated octaves at roughly 4,000 Hertz, 8,000 Hertz, and 16,000 Hertz. Though this content changes over the duration of the piece, sustained pitches remain in those frequency ranges until the end. This division of intervallic space is reminiscent of the content in Section I. In Radigue’s writing on Phi 847 she poetically states, “Distance between Proximity and Familiarity.” This phrase may be interpreted as the distance between a subject’s placement and how well the subject is understood. In Section III, the listener is receiving new content, but has heard content like this before. For example, the descending melody is new, but it is utilizing the timbre of the bell in Section II; sustained sounds separated by octaves or near octaves in the 4,000 to 16,000 Hertz range have occurred before; and the overall timbre and amplitude of Section III

Figure 5.5: Section III, 42:00-52:30
reflects that of Section I. This new content, though familiar, has been separated from its first introduction by a great temporal distance -- 25 minutes to be exact. Radigue may be playing out these different measurements by presenting content that is close in its familiarity but far in its temporal relationship to when it was first introduced. In addition, there is a great distance in the intervallic space that the content of Section III spans, but there is tremendous familiarity in the octave relationships. The phrase “Distance between Proximity and Familiarity” suggests that these two ideas each address relationships but separate measurements.

In Section IV, the listener is presented with the densest content of the piece. This is made visually apparent by the spectral analysis that appears below:

![Figure 5.6: Section IV, 52:30-1:11:00](image)

Unlike Section I and III, the frequency range is no longer cleanly divided. This cloud of sound centers around 3,600 Hertz where the content with the largest amplitude is heard. This texture continues in an almost static manner for just under twenty minutes, illustrating both Kramer’s idea of “vertical time” and Radigue’s phrase “time
suspended within the time unit.” For an extended duration of nearly twenty minutes, there is a seemingly static texture with micro-fluctuations that are not heard as separate events. The content is perceived as high probability information because similar timbres throughout these frequency locations have not been heard previously in the piece. The listener’s familiarity with such content and the intervallic distance between frequencies gives another example of the “Distance between Proximity and Familiarity.” The subtle frequency and amplitude modulations are heard as small fluctuations but not separate sounds, events or changes. This could be the “Quivering, murmur of sound material,” or perhaps the near stasis but constant fluctuation of the texture is Radigue’s suggestion of an “Impossible taming.”

In Section IV and each of the preceding sections the sound’s near stasis slows the perceived rate of time passing in a similar manner as The Days Run Away. By sustaining sounds or textures for upwards of twenty minutes, the information density is far below the listener’s upper limit. Though some of the information presented in the piece may be “surprising,” Radigue’s mixing techniques allow for the information to be presented at such a gradual pace that it remains high probability. Even though Section IV presents an incredibly dense texture, its sustained static presence for twenty minutes allows the information to be reduced to high probability. Whereas Garland uses high probability diatonic content and repetition to slow the perceived rate of time passing, Radigue chooses to use long durations in order to reduce information density and slow the perceived rate of time passing.
Radigue writes the phrase “time suspended within the time unit.” Because of the tools that Radigue uses in her compositional process, I would suggest that Radigue’s practice is uniquely tied to a unit of clock time. Radigue makes clear in interviews that her composing starts with making the desired sounds on the synthesizer, recording those sounds to tape, and then finally creating a mix of all the tapes. When magnetic tape is played back, it is rotated at a specific rate in order to remain in tune. This rate of rotation happens in relationship to clock time. Many tape machines use potentiometers or sliders in order to control the speed of rotation in relationship to inches per second. Throughout Radigue’s mixing process, clock time is ever-present. In order for time to be suspended in such an environment, or in order to alter a listener’s subjective perception of time, the suspension or stretching needs to be done in relationship to a clock time unit. This interconnection exaggerates the compositional process’ relationship to a practice of measurement by organizing the sonic materials against an ever present unit of measurement, clock time.

The usage of magnetic tape, which ties Radigue to clock time, was new to composers of the twentieth century. Its recording capabilities and its malleability created new opportunities for composers. Magnetic tape’s direct relationship to clock time allowed composers to conceptualize the temporal aspects of their music in new ways. Discussing such temporal reconfiguring, musicologist Roger Matthew Grant writes, “we must bear in mind that theories of meter were the result of a deep interconnection between historical actors, the world they experienced, and their
techniques for manipulating and measuring it. These techniques involved timekeeping practices that were means of moving through the world and organizing life’s unfolding. As ways of relating to the world changed, so too did techniques for understanding time and constructing meter” (Grant, 8). Musical tools such as magnetic tape facilitated a reconfiguring of the temporal aspects of music by allowing time to be directly measured by its rotation speed, inches per second. Time could then be manipulated in relationship to that speed through division, multiplication, and the playing of multiple tapes at different speeds, among others. In addition to magnetic tape, the synthesizer offered unique temporal possibilities. The ARP 2500 which Radigue used to create Phi 847 uses the temporality of electrical current for a multitude of purposes: creating oscillation, triggering new content in a sequential pattern, and filtering. The temporality that controls systems within a synthesizer adds a periodicity to the music’s unfolding. Utilizing the temporality of electrical current can be seen as analogous to the pipe and reed organs’ usage of blowers and air pressure. In the case of acoustic instruments other than the organ, there are two actors: the instrument and the performer. In the case of the synthesizer and the organ, there are three actors: the instrument, the performer, and electrical current/air pressure. Each actor presents its own unique behavior and constraints. The synthesizer’s ability to work with the temporality of electrical current was new to musicians of the twentieth century. Electrical current’s temporality and magnetic tape’s direct relationship to clock time allowed musicians, composers, performers,
and listeners to reconfigure their understanding of musical time. The new questions that may have resulted from this reconfiguring could have supported Radigue’s development of concepts like “slow stretching” or “time suspended within the time unit.” In my own composition, *Recounting*, I utilize the previously discussed temporal possibilities of the pipe organ and its third actor, air pressure, in conjunction with the exact repetition and modular structure used by Peter Garland.
Recounting

*Recounting* was written for solo organ with an interest in blending Brün’s idea of manipulating the listener’s temporal perception (by shifting the rate of time and events) with Garland’s modular structure of repeated, high-probability information. The piece has an ABABA form. The A sections feature sustained tones of an open duration. The B sections are a series of measure-long segments (though occasionally two or three measure-long segments) which may be repeated as many times as the performer wishes. Each staff represents a different manual on the organ. With the exception of a few transitional segments, each hand in the B section is given a different rhythm. The overall ABABA form is a rhythm and a repetition of its own. Once the second B section has been reached and the listener is made aware of the piece’s cyclical nature, there is a suggestion that the cycle may happen again. By suggesting that the piece is cyclical and that its form is a rotation between A and B, the piece may be mentally extrapolated into the future. Perhaps the cycle could be endless. The second A section, though it is different in its harmony, gives a sense of recounting the section’s first appearance. Brün suggests that recapitulation gives “the impression… that no time at all had passed” (Brün 33); by allowing the sections to be revisited or by “recounting” them, there may be a suggestion that time has not moved forward in my piece as well.

In *Recounting*, the harmonic language resists a tonal center without becoming overly dissonant. These compositional decisions favor perfect intervals, major
seconds, major ninths, and using sixths instead of thirds. There are many instances where harmonic seconds occur in the bass clef. This should likely be considered dissonant: in the bass clef, the interval is inside of the critical band. However, given the length of time that each harmony is sustained, either through a long tone in the case of the A section, or repetition in the case of the B section, the relationships meld and are largely not perceived as opposing one another.

Looking specifically at the rhythmic content in the B section, in the transition from segment I to II, the two manuals move from playing in rhythmic unison with one another, each playing constant quarter notes, to manual I playing six quarter notes in the time of manual II’s five quarter notes:

![Figure 6.1: segment I and II](image-url)
Using Brün’s framework, the amount of events within a given amount of time increased. Each of the two manuals are equal in volume and the registers are intertwined (manual I using 4’ and 8’ flutes, manual II using 4’ and 8’ string, and a 16’ subbass in the Pedal). Through the segment’s repetition, there is an effort to create the effect that either of the two manuals could be stating the pulse of the piece. The time becomes both six and five. As the exact repetition continues, the pulse of the piece becomes the segment’s downbeat, turning the segment into a large “1,” where the pulse is the time it takes for the two manuals to join each other. As the segment repeats, the discernible event is no longer the counter rhythm phasing against the quarter note, but instead the event becomes the slow transition between each segment.

In segment VI, the counter rhythm moves back and forth between playing six notes against the 5/4 quarter note and playing four notes against the 5/4 quarter notes.
Figure 6.2: segments V and VI

Here, the amount of events is shifting over a consistent unit of time. Initially, when the piece moves from segment V to segment VI, there is a noticeable change. The events within a consistent time unit fluctuate between getting faster and slower. This fluctuation aligns neatly with Brün’s idea of altering our temporal perception by shifting the quantity of events within an amount of time. Through repetition, each measure begins to be heard as a totality and what is perceived is simply the shifting rate of events. After continuous repetition, what is heard as “the event” is the two measures combined. At this point, the content that is being played contains no new information and all of the content is high-probability information. What is left is the anticipation of the next segment. These transitions become the piece’s larger pulse as the next segment is anticipated. This shift in temporal focus suggests four temporal registers:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>The varying lengths of the counter rhythm as they are juxtaposed against the quarter note.</td>
</tr>
<tr>
<td>II.</td>
<td>The internal cycling of the segment; the length of the entire segment.</td>
</tr>
<tr>
<td>III.</td>
<td>The segments within the B section slowly moving from one to the next.</td>
</tr>
<tr>
<td>IV.</td>
<td>The cyclical form shifting between the A section and the B section.</td>
</tr>
</tbody>
</table>

Figure 6.3: four temporal registers

During each transition to a new segment, these registers appear in this order until all four are in focus. As the listener is guided through these four registers of temporal
perception, their sense of the rate of time passing may be progressively slowed. When new content is presented for the first time, it is surprising and low-probability. As a result, it may be near or above the upper limit of what one can process in a given amount of time. The long duration of each sustained tone in the A section, and the exact repetition in the B section, aids in the processing of this low-probability information. As the sounds continue to sustain and repeat, they become completely predictable and contain zero information. Now the listener is receiving information at a rate far from the pace at which it is usually desirable to convey information, and therefore the listener’s perception of time begins to slow. This perceived rate of time passing continues to decrease as the other temporal registers come into focus.

In order for something as simple as a cross-rhythm to contain low-probability information, it must be surprising on some level. For the rhythm to be surprising it must be uncommon to that particular listener; if it is uncommon, there may be a reason why it is generally avoided. Potentially, some rhythms may be inherently dissonant, or the rarity of their usage causes many listeners to find the sounds foreign. I personally find that six in the time of five, seven in the time of three, and seven in the time of four all create a sense of vertigo (each of these rhythms are used in *Recounting*). Each of these rhythmic ratios are very close to a stable rhythmic resolution. In the case of six in the time of five in segment II, or five in the time of six in segment XIX, a dissonance is created as the events seem to be speeding up or slowing down but then consistently resolve. This is not dissimilar to way a dominant
V chord asks to move to the tonic. The counter rhythm seems to ask to join the quarter note.

Similarly, seven in the time of three and seven in the time of four ask to become the eighth note (meaning the seven will become six in the case of the three and the seven will become eight in the case of the four).

Figure 6.4: segments II and XIX
When I began writing about temporal relationships, I wanted to objectively explain my own sense of vertigo. By invoking vertigo, I mean a loss of balance. For a sound to be unbalanced suggests a dominant feel, while to be balanced is to be the tonic. Initially, I thought the answer to this rhythmic vertigo lay in Henry Cowell’s suggestion that rhythmic relationships and harmonic relationships come from the overtone series and that our perception of rhythm is tied to our perception of harmony. This claim is certainly true on a micro-level -- the sound waves creating a major third have a five against four relationship -- but in the previously mentioned rhythmic ratios, their intervallic counterparts are in fact consonant (6/5 being the minor third, 7/3 being a perfect eleventh, and within Just Intonation studies the 7/4 or the septimnal seventh is perceived as a consonant (Dotty, 20)). What I experience subjectively is that each rhythmic ratio involving a prime number of five or higher wants to resolve to the closest whole number (meaning 7/3 wants to become 6/3 which reduces to 2). I was in search of an explanation to this subjective feeling while conducting the research that informed this thesis, however I did not find an answer.
within the context of Just Intonation and temporal perception. This absence led me to believe that the answer was more within the context of Information Theory. Rhythmic ratios that involve the prime number five or higher may be rare enough that they are always perceived as low-probability information. Exposure seemed the only way to test whether, after the ratios become high-probability information, they then no longer have a dominant feel. *Recounting* was partially written to deeply immerse myself in these rhythmic ratios.

When writing for organ, spatialization is unavoidable, due to each organ’s unique pipe placement. Part of the registration used in the A section of *Recounting* is divided on the left and right sides of the organ in Memorial Chapel, Middletown, CT (where the piece was composed and premiered). Manual I uses an 8’ Violone, this is not divided on each side of the organ but instead centered inside the positive box, while Manual II features the 8’ Harmonic Flute which is toward the front of the organ on the left and right sides. The Harmonic Flute stop is divided in half on both sides of the organ, featuring all the pipes in the C whole tone scale on the left side and all the pipes in the C# whole tone scale on the right side. Applying the *kappa effect*, when two notes whose pipes are physically close together are played in succession, the notes will be perceived as being temporally closer together. Both the *kappa* and *tau effects* explore the interdependence of temporal and spatial perception, however, the physical properties of the pipe organ asks us whether spatial qualities effect intervallic perception (the effect of space on intervallic space). We know that a sound
with a longer wavelength will require a larger distance to complete an oscillation. As a result, lower notes played on the organ timbrally sound different from further away. Considering our ear’s ability to hear this distance unfold in regards to timbre and remembering modified auditory motion’s imagined object traveling to different frequency location, we may hypothesize that physical space may affect intervallic space.

These effects alter our perception in minute ways; however, what they offer in a larger sense is that, if sound is essential to a particular piece of music, then space remains an equal and interrelated centerpiece. For a listener to perceive music, their body must be in contact with the sound and therefore in the space. The movement of sound between different organ pipes gives the listener multiple reference points that may be used to aid them in locating their body in that space. One may more or less abstractly locate themselves in space with one sound source, through its reflection off of the various walls (or lack thereof), but through multiple sound sources, one may locate themselves more precisely. Therefore, one use of music is as an aid to locating our bodies, to becoming aware of oneself.

This idea is a theme explored in the “(Soma)tic practices” of poet C.A. Conrad; these practices -- routine, ritualized protocols for interacting with the world -- cause the poet to be hyper-present and therefore aware of themselves. In starting the project, they aimed to create practices “where being anything but present was next to impossible.” They explained,
“These rituals create what I refer to as an “extreme present” where the many facets of what is around me wherever I am can come together through a sharper lens. It has been inspiring that (Soma)tics reveal the creative viability of everything around me” (Conrad, Ecodeviance, xi).”

Beyond bringing oneself into the “extreme present,” these practices enabled the poet to create their art: “I cannot stress enough how much this mechanistic world, as it becomes more and more efficient, resulting in ever increasing brutality, has required me to FIND MY BODY to FIND MY PLANET in order to find my poetry” (Conrad, Beautiful Marsupial, 1). Similar to the ritualized structures that C.A. Conrad uses in order to access the “creative viability of everything around” in order to locate bodies in space, by listening to music one may be made aware of one’s self and one’s location. On some level, though minute, musical practices such as playing the organ and hearing sounds move between pipes, playing a guitar or string instrument and feeling the instrument resonate, or interacting with loudspeakers, are reminders and celebrations of one’s own physicality.
Reciprocal Harmony

Reciprocal Harmony is an ongoing series based on a tuning system that I developed through my solo guitar practice. The technique, which involves floating a humbucker guitar pickup above the first fret, was adapted from guitarist Fred Frith (for an example hear Fred Frith, Guitar Solos, 1974). This alternative pickup placement allows for the amplification of both ends of the guitar string. Because of the pickup placement, if the string is tapped instead of plucked the string resonates from both sides of the fretting finger. Each attack results in a dyad. As the fretting hand moves up the neck on one string (from the headstock toward the bridge), the notes ascend within the 12-note equal tempered scale (see fig. 7.1). On the opposite side of the finger (between the fretting finger and the headstock), the sound descends as the hand moves up the neck. The notes descend in a reciprocal relationship to 12-note equal temperament (see fig. 7.4). (Tremendous thanks to both Ron Kuivila and Matt Wellins for helping me work through the math that lay behind this tuning system.)

Semitone values moving one octave up a string:

[ open string (1), 1.0594630943593, 1.1224620483094, 1.1892071150027, 1.2599210498949, 1.33483985417, 1.4142135623731, 1.4983070768767, 1.5874010519682, 1.6817928305074, 1.7817974362807, 1.8877486253634, 2 ]
Figure 7.1: equal temperament semitones

The reciprocal of the ascending equal tempered semitone values are the descending equal tempered semitone values:

[ open string (1), 0.94387431268169, 0.89089871814034, 0.84089641525371, 0.7937005259841, 0.74915353843834, 0.70710678118655, 0.66741992708502, 0.62996052494744, 0.59460355750136, 0.56123102415469, 0.52973154717965, 0.5]

Figure 7.2: descending semitones

These semitone values do not account for the finger’s placement on the string. For example, it would be impossible to make a sound on a string that is lower than its open frequency. In order to account for the finger’s placement on the fingerboard/fretboard the reciprocal semitone values must be subtracted from 1, and then the reciprocal of those values must be taken:

1 - descending semitone values:
reciprocal harmony semitone values:

[ open string (1), 17.817153745106, 9.1657951488262, 6.2852135078832, 4.8473221018631, 3.9865023160958, 3.4142135623731, 3.006794698297, 2.7024143839193, 2.4667212021806, 2.2791037084458, 2.1264449996649, 2]

If these semitone values are multiplied by the frequency of the open string, the result is the hertz frequencies of the string resonating between the finger and the headstock as it moves up the neck chromatically. The following values are in relationship a string tuned to A 220 Hz:

[ open string (220), 3919.77, 2016.47, 1382.74, 1066.41, 877.03, 751.12, 661.49, 594.53, 542.67, 501.40, 467.81, 440]
As the finger moves the twelve steps up the neck and reaches the octave, the frequency is the same on both sides because the string has been divided in half. Where the string traditionally sounds the fifth above the open string, there is a fifth on both sides of the finger. However, behind the fretting finger the fifth sounds an octave higher. The intervallic ratio for a fifth is 3/2, dividing a string into one third and two thirds results in two fifths separated by one octave. Where the string traditionally sounds a fourth above the open string, behind the fretting finger the sounding pitch is two octaves above the open string. The intervallic ratio for a fourth is 4/3, dividing a string one quarter and three quarters results in a perfect fourth and two octaves above the open string. Because moving up the string is in relation to 12-note equal temperament instead of justly tuned intervals, the divisions of the string are not exactly one-third or one-quarter, and as a result there are slight cent deviations from the perfectly tuned intervals.

The previous values are calculated on a fretless string instrument. When frets are involved, the previous semitone values should move forward one step -- meaning
if the finger is placed on the second fret, what resonates behind the finger is actually resonating between the first fret and the headstock. Thirteen half steps are required to produce an octave between the finger and the headstock on a fretted instrument.

[open string (220), first fret - no sound is produced, second fret - 3919.77, third fret - 2016.47, fourth fret - 1382.74, fifth fret - 1066.41, sixth fret - 877.03, seventh fret - 751.12, eighth fret - 661.49, ninth fret - 594.53, tenth fret - 542.67, eleventh fret - 501.41, twelfth fret - 467.81, thirteenth fret - 440]

Figure 7.4: reciprocal harmony for fretted instrument represented with its cent deviation from the closest equal-tempered pitch

These Reciprocal Harmony experiments and measurements restage the monochord studies that early mathematicians undertook in order to gain insight into tuning systems. Though Pythagoras is largely given credit for the intonation studies on the monochord, the instrument and similar investigations most likely took place prior to his involvement (Terpstra, 138). At the heart of Reciprocal Harmony is the idea of precisely dividing a string in order to create intervallic material. This same idea is at the root of the monochord investigations that led to “the ancient science of HARMONICS, which had its applications in tuning theory, arithmetic, geometry, and
astronomy” (Terpstra, 140). Though for me the original idea for *Reciprocal Harmony* came from seeing guitarist Fred Frith perform, its origins go back to Babylonia or ancient Egypt (Terpstra, 138).

The first piece I wrote using this tuning system simply called for the pickup to be placed above the first fret of the guitar and instructed the performer to play with both hands on the fretboard. *Reciprocal Harmony with Percussion* adopted these harmonies but took them beyond the context of the guitar. The piece was composed with a guitar in a very similar fashion to the previous solo guitar works, however the equal tempered content was given to a piano and the reciprocal harmony was executed on a keyboard that had been reprogrammed to play the microtonal content. I added cello and percussion parts to act as accompaniment. Though this piece was aesthetically and sonically a success, it did not demonstrate the reciprocal movement of the tuning system because six different open string root values were used in its construction and none of these open strings related to the ensemble. The piece was essentially a transcription of a guitar technique.

*Reciprocal Harmony No. 2* for viola and MIDI keyboard attempted to address this issue by utilizing only one string length (the c-string of the viola), and having the viola part be a combination of half steps, whole steps, and large leaps. The keyboard would simply play the reciprocal frequencies in the hopes of making clear the tuning system through the two instruments’ constant contrary motion. *Reciprocal Harmony No. 3* for electric guitar and alto saxophone returned the tuning system to the guitar,
but the microtonal reciprocal harmony was reinforced by the saxophone through alternate fingerings which create approximations of the reciprocal content.

Measurement exists throughout this tuning system in multiple ways. These harmonies are created through a clear physical measurement -- the division of the string. As the division of the string changes, the two harmonies move with a reciprocal motion to one another. Musical intervals are created through a difference in the rate at which a sound wave vibrates. This vibration is a movement. Movement is a change in position (space) over a period of time (Lockhart, 201). Musical intervals are therefore interconnected with a concept of space. The kappa effect explains how physical distance and intervalllic distance are both subject to modified auditory motion and are perceived in a similar manner. In the case of the various Reciprocal Harmony pieces, the measurement of the physical distance (on the string), is also a measurement of intervalllic distance. Perception of these intervalllic distances is also perception of physical distance. Reciprocal Harmony makes obvious the interconnection between intervalllic space and physical space which the kappa and tau effect have demonstrated in the context of cognitive science.
Conclusion

In *The Days Run Away, Phi 847, Recounting*, and each of the *Reciprocal Harmony* works, sound is presented over a period of time. If one resists the convenience of clock time and allows subjective temporal perception to create the temporal units, then the characteristics of the music will guide the temporal perception of it. By discerning separate characteristics in the music, and noticing their discrepancies, one is measuring the music against itself and other music the listener may have heard. As life unfolds while listening to music, the listener measures these discrepancies and similarities in order to process the information. A sound wave is a vibration. This action is a movement. Movement is tied to space and time (Lockhart, 201); therefore measurements are both temporal and spatial. If the intersection of time and space is where music resides, then there should be ways to be musical that exclusively focus attention on those two dimensions. The action that allows one to perceive music’s spatial and temporal dimensions is measurement. By measuring time and space, we participate in music.

With this framework, I would suggest that using a calendar is musical. While perceiving a piece of music, separate events or discernable characteristics help one create units for measurement. Gravitational forces in the universe present consistent temporal units in the form of planetary rotations and orbits. These manifest themselves most overtly in the setting and rising of the sun, the changing of the seasons, and the shifting in the stars and moon. These cycles have been mapped
differently by different cultures resulting in differences in how in temporal cycles are represented. What is musical about the creation of calendars is that they attempt to measure the temporal unfolding of our lives in relationship to the larger universe, while forming a spatial measurement of our location within the knowable universe. The ability to locate this planet and others within the universe depends on the knowledge of the planet’s movement. This movement is a guide for both perceiving time and space. To participate in the ritual of using a calendar is to participate in music.

As we measure time and space, ritualized structures such calendars, habitual domestic routines, and musical practices are often employed in order to engage with time’s unfolding and our surroundings. In this context, I define a practice as a method, a set of tools, or a strategy, used in an often consistent manner that is both forward-looking and/or historically reflective in its posture. For example, I play various altered scales with a metronome consistently over the course of a period of time and there is an increase in comfort with the scales and the velocity at which they can be played: this is a method used in a consistent manner that is both forward-looking (toward the development of a skill) and historically-reflective (given the long history of rehearsal and “practice” in music history). The consistent usage of a calendar progresses toward and anticipates the future while situating the user in space. In addition, to positioning the user temporally and spatially in reference to the
planet’s orbit, the liturgical calendar used by the Catholic Church places the user in historical space in reference to the life of Jesus.

The Catholic practice of using a Rosary is a ritualized structure that utilizes both the liturgical calendar and exact repetition of well-known prayers in order to guide the practitioner into “restful and contemplative prayer” (USCCB, “How to Pray the Rosary”). The ritual both reflects on the past by meditating on Jesus and Mary’s life, and remains forward-looking by anticipating Jesus’s return through meditation and acknowledging one’s own death through prayer. Through the exact repetition of specific prayers (which are reminiscent of the exact repetition in The Days Run Away and Recounting), the Rosary slows the practitioner’s perception of time while locating them in historical space (after the life of Jesus and Mary and before one’s own death).

Below is a representation of the Rosary’s form using music notation:
The United States Conference of Catholic Bishops state that, “the repetition in the Rosary is meant to lead one into restful and contemplative prayer related to each Mystery. The gentle repetition of the words helps us to enter into the silence of our hearts, where Christ's spirit dwells” (United States Conference of Catholic Bishops, “How to Pray the Rosary”). Words such as restful, contemplative, and silence suggest a slowing. Similar to The Days Run Away, our perception of time is slowed through exact repetition. The words repeated during the rosary are known well to the practitioners, and therefore carry high probability information. The repetition of these words creates a state of sustained low information density. Through this lack of
surprising information, the rate of time passing slows down. The Mysteries of the Rosary situate the practitioner inside of the seven day calendar cycle. The Mysteries are specific stories and topics that the practitioner meditates on while praying the Rosary. The day of the week and time of year determines which mystery is meditated on. The calendar is a method for measuring the planet’s movement and therefore it is temporal and spatial. Through the Rosary’s connection to the calendar, the practice becomes both temporal and spatial. The rotation of the Mysteries changes during Advent and Lent, placing the Rosary within the larger cycle of the year, therefore locating the practitioner in the planet’s yearly orbit as well. Apart from calendar cycles, the Rosary locates the practitioner in history. In practicing the Rosary, practitioners are reflecting on past events -- the lives and deaths of Mary and Jesus. An event being in the practitioner’s past is a temporal measurement. With the repetitions of the Hail Mary, the Our Father, and The Assumption in the Glorious Mysteries, the practitioner meditates on their own death. This places them temporally before their death, measuring the temporality of their life. If the Rosary practitioner locates themselves in the context of historical events (such as the death of Mary and before their own death), they are one coordinate on a temporal plane running between the two events. This mapping is not dissimilar from the measurement of other dimensions. One or more vectors could be created and the coordinate could be measured in comparison to a selected origin.
The Rosary’s form is strikingly similar to traditional musical works of western classical music. The ABC form of the rosary -- where A is everything leading up to the five decades, B is the five decades, and C is the *Hail, Holy Queen* and *Sign of the Cross* -- is reminiscent of the exposition/development/recapitulation of sonata form. The repetitions in the decades suggest a rhythmic structure similar to conventional musical meter. In addition to looking at the Rosary through the lens of Information Theory, the practice aligns with Brün’s events/time structure by looking at prayers that are repeated, prayers that occur only once, and prayers that re-occur but are not directly repeated.

Returning to two suggestions made at the beginning of this thesis -- that the perception of bodies in a space is essential to music; that if sound can be removed from the conception of music, one is left with a measurement of time -- the usage of a calendar, the Rosary, and the measuring of the bedroom all align themselves with the first idea of music. Both the calendar and the Rosary do so while removing sonorous qualities (assuming the Rosary prayers were said in the practitioner’s mind and not out loud). The usage of a calendar and the Rosary are both directly tied to space through their connection to the yearly cycle which is, in turn, tied to the rotation of the Earth around the Sun, and therefore the practitioner’s placement in the universe. However, if sound is removed from music, there may be other ways to conceptualize music that are entirely temporal. For example, I would suggest the following composition:
Each time I have performed this piece I needed to actively ignore spatial dimensions. The sound of cars passing my apartment made me aware of the physical space I lived in. The physical sensation of my feet touching the ground was an inescapable reminder of the reality of my own physicality. Intellectualizing time “moving” forward without a spatial dimension requires actively resisting the urge to conceptualize time as space, meaning visualizing movement on a line or an imagined physical plane. Though a composition such as *Temporal Music* is real and imaginable, its realization seems impossible. Often when one conceptualizes time they do so utilizing spatial metaphors, highlighting the two dimensions’ interconnection. In addition, in the first line of the score the receiver is asked to perceive time moving forward and then repeat that action. It is possible to imagine repeating a period of time, however, due to life’s constant temporal unfolding it is impossible to do so. *Temporal Music*’s difficulty stems from the conscious and subconscious awareness of other subjects. Awareness of one’s self -- often stemming
from the awareness of others in the context of music -- can cause the receiver to be simultaneously measuring the temporal unfolding of the music in relationship to their temporal lives unfolding. Awareness of music, where music is a subject outside of the self, reminds one of the physical space they inhabit.

By suggesting that music can be a measurement of time and space, I have attempted to reframe how someone might participate in music. This reframing makes suggestions on how music acts upon the receiver and how music can be used by the receiver to measure time and space. There have been proclamations as to what music is and is not throughout the history of music theory. Discussions of what music can be suggests other new possibilities and creates space for existing works. The idea that music can be a measurement of time and space does not negate any of these ideas but instead attempts to sit inside of other ideas and say “yes and also.”
recounting

recounting is a solo organ piece that attempts to slow the listener’s perception of time passing. Each of the A sections may be played for as long as the organist wishes. Every repeated measure or grouping of measures in the B sections may be repeated as many times as the organist wishes. The organist may pause during the transitions between the A and B sections. The average performance length is twenty-five minutes but the specific duration is completely open to the organist’s interpretation.

Manual I, manual II, and pedals may have any registration, however, the two manuals and pedals should be equal in volume. The organist is encouraged to find a registration that is highly spatialized, perhaps bouncing back and forth between the left and right sides of the organ or different places in the space.

D. Scanlon
B. 1

I. \( \dot{\text{r}} = \text{roughly } 60 \)

II.

III.

IV.

D. Scanton
rubato, significant pause in manuals between each change
ending of B. 3, slight ritardando, no repeat

A. 3 rubato

D. Scantlon
Characters in a Play

for solo guitar

Each measure is repeated as many times as the performer wishes. In general, the piece should move from measure I to measure XXII, however, the performer is welcome to move freely between neighboring measures. For example, from measure III the performer may move freely between measures II, III, and IV. The piece should be played as fast as the performer feels they can confidently perform it. This piece is performed with a pick-up or microphone floating above the first fret of the guitar in order to amplify the pitches ringing between the tapping fingers and the headstock.

Jare Leandon
Reciprocal Harmony with Percussion

"Reciprocal Harmony with Percussion" is a chamber work written for Piano, Cello, Percussion, and MIDI Keyboard. The MIDI Keyboard is to be performed on a four-octave MIDI keyboard. The MIDI Keyboard's written pitches are for performance purposes only. The MIDI keyboard and its sounding pitches will be controlled with the following SuperCollider code:

```
<lowkey = 36;
--freq = (@\(156.0697075293, 164.82, 189.000459223, 198.3580058773, 224.7995508664, 250, 261.6255782228, 266.7293508815, 277.1832863582, 293.66, 329.505880167, 349.22, 391.9957557512, 418.6088339775, 440, 466.2077598854, 493.88, 523.25490746, 554.23731658, 587.3298969345, 622.25129203, 659.25524927, 711.174143817, 750.0988148083, 783.9988849349); MIDIClient.disposeClient;
MIDIin.connectAll;

 SynthDef("note", 1, var audio = SynthCtrl.ar(freq, amp, gate, 4, amp);
 audio = Pan2.ar(audio, pan, LinOut.ar(1.0, 0.04, 7.0));
 Out.ar(out, audio);)

\)
--melody = 76;
--noteOn = [ var, num, chan, src ];
--noteOff = [ var, num, chan, src ];

--melody[76] = SynthDef("sine", [Freq = freq(num, lowkey: max 0), amp: var(255).squared(), src]);
\)

 --melody[76].noteOn(76, 32, 8, 419.9957557512);
 --melody[76].noteOff(76, 32, 8, 419.9957557512);
```

Each measure that contains repeat signs will be played as long or as short as the performers wish. The pianist will cue the ensemble to move on to the following measures. The percussion part is meant to be played on our wood block, written in the second space from the top of the percussion clef, and one bowed medium sized steel tom, written in the bottom space of the percussion clef.

73
RECIProCAL HARMONY NO. 2
for viola and MIDI keyboard

Reciprocal Harmony No. 2 is an intonation study for viola and a two-octave MIDI keyboard. The entire piece should be played on the viola’s C string. The MIDI keyboard’s written pitches are for performance purposes only. The MIDI keyboard and its sounding pitches will be controlled with the following SuperCollider code:

```
( ~lowkey = 48;
  ~freqs = [(329,255333333333, 335,91144464306, 343,25567246435, 351,41685652906, 360,48596335396, 370,61937968174, 381,99597059783, 394,83662877648, 409,41740474761, 426,0878893823, 446,2947470123, 467,63373519874, 493,888, 525,1043282176, 562,8018976359, 609,13213666649, 667,33420796504, 742,49788279746, 843,10589709241, 984,42688193671, 1196,9977198341, 1552,0706236367, 2263,4014540511, 4399,7679458164]);

SynthDef("sine", { | out, freq, amp, gate = 1, pan |
  var audio = SinOsc.ar(freq,0 , amp);
  audio = Pan2.ar(audio, pan, Linen.kr(gate, 0.001, 1, 0.04, 2));
  Out.ar(out, audio); }).add;

SynthDef("sine1", { | out, freq, amp, gate = 1, pan |
  var audio = SinOsc.ar(freq,0 , amp).distort;
  audio = Pan2.ar(audio, pan, Linen.kr(gate, 0.001, 1, 0.04, 2));
  Out.ar(out, audio); }).add;

SynthDef("sine2", { | out, freq, amp, gate = 1, pan |
  var audio = SinOsc.ar(freq,0 , amp);
  audio = Pan2.ar(audio, pan, Linen.kr(gate, 0.001, 1, 0.04, 2));
  Out.ar(out, audio); }).add;

~synths = ();
~sd = \sine1;
~noteOn = [] | { vel, num, chan, src | 
  ~synth[num] = Synth~.sd{freq: ~freqs[num - ~lowkey max: 0], amp: (vel/255).squared * 2);};
  ~noteOff = [] | { vel, num, chan, src | ~synths[num].release; ~synths[num] = nil;};
  ~clear = { ~synths.keys.do | k | ~synths[k].release; ~synths[k] = nil } | MIDIdef.noteOn(~noteOn, ~noteOff);
MIDIdef.noteOff(~noteOff, ~noteOff);
( ReplaceOut.ar(0, Limiter.ar(in.ar(0, 0.2), 0.5)); ).play(addAction: \addMtof;)
)
```

Except for melodic cell X, each melodic cell should be repeated as many times as the performers wish. Either performer may cue to move on to the following melodic cell. The viola and the MIDI keyboard should remain equal in volume. The tempo should be slow, no faster than sixty beats per minute. Reciprocal Harmony No. 2 explores the harmony that exists on both sides of a divided string.

DAVE SCANLON
RECIProCAL HARMONY NO. 2

I.

II.

III.

DAVE SCANLON
RECI PROCAL HARMONY NO. 2

VII.

VIII.

IX.

DAVE SCANLON
Reciprocal Harmony No. 3

For Alto Saxophone and Electric Guitar

Dave Scanlon, 2018

Performance Instructions:

Each repeated measure in Reciprocal Harmony No. 3 may be repeated as many times as each performer wishes. The two performers do not need to move on to each consecutive measure together. It is fine for the two performer to be at times on different measures, however, the two musicians should move through the piece loosely together.

The tempo of each phrase may be decided by the performers individually. The two performers do not need to be playing the measures at the same tempo and each measure may have its own unique tempo.

Dynamics and articulation may be freely improvised.

Every note in the Electric Guitar part must be tapped on the fretboard. The Electric Guitar must use an additional guitar pickup floating above the first fret in order to amplify both ends of the resonating string.

The Alto Saxophone should use the alternate fingerings when provided.

The duration of the piece is open to the performers.

D. Scanlon
Bibliography:


