A Computer Application to Explore 53-Tone Equal Temperament Harmonies Through Modal Interchange

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Abstract

We present a novel computer application for real-time exploration of microtonal harmonies through intuitive visualization and integrated MIDI controllers, bridging theoretical concepts and practical musical applications. We extend modern harmonic principles from 12-tone equal temperament (12-TET), incorporating interval distinctions from 31-TET (subminor, neutral, supermajor), and further expanding into detailed harmonic possibilities of 53-tone equal temperament (53-TET). Our application leverages modal interchange and parallel chord substitutions, offering intuitive navigation through microtonal harmonic trajectories. The implementation utilizes MIDI Polyphonic Expression (MPE) via our custom *MaxForLive* application, *The Bridge*, ensuring precise microtonal control and compatibility with digital audio workstations (*Ableton Live 11/12*). The system includes real-time visualization, interactive chord manipulation, and a comprehensive Scale Editor for harmonic experimentation. Through practical examples and theoretical analysis, we demonstrate how this approach reveals new harmonic possibilities while maintaining connections to established modal frameworks. This research contributes to the growing microtonal music field by providing theoretical foundations and practical tools that incorporate extended tuning systems into contemporary musical practice.

Keywords

Microtonality, Music Theory, Modal Interchange, Harmonic Exploration, 53 Tone Equal Temperament, Data Visualization

1 Introduction

Digital Audio Workstations (DAWs) such as *Ableton Live* have made strides in incorporating microtonality, allowing users to experiment with extended tuning systems through features like piano rolls with microtonal pitch adjustments. However, these implementations are constrained by the limitations of the MIDI protocol, which was designed for the 12-tone equal temperament (12-TET) system. Microtonal tuning in such environments often requires compromises, such as reducing the available pitch range when distributing the MIDI range into more detailed pitch distributions per octave.

Although extensive theoretical frameworks for microtonality exist [4, 12, 13, 25]—and microtonal practices have been embraced by composers and instrument makers around the world—the potential of microtonal chord progressions, particularly the nuanced spectrum of chord qualities and their functional relationships, has not been fully exploited in digital musical interfaces. In many traditional and contemporary musical contexts, microtonality is a common feature; however, the specific domain of extended chord quality variations within microtonal systems offers a richer palette of harmonic textures that challenge conventional tonal relationships. Existing tools in DAWs often lack the intuitive interfaces and computational support necessary for composers and performers to explore and manipulate these subtle yet expressive harmonic possibilities in real time.

This paper presents a computer application for real-time microtonal harmony exploration. The system comprises an interactive interface with an 8x8 grid for composing chord progressions, scale, chord editions, and a voicing editor. This interface is controllable through a MIDI controller (launchpad MK[3]). Unlike traditional fixed-template approaches, this project enables users to experiment with harmonic relationships by applying modern concepts like modal interchanges and parallel chord substitutions to microtonal contexts. This design philosophy allows musicians to discover new harmonic possibilities from a clear theoretical framework. Supplemental material, audio examples, and the application are available on the project's web page. https://fifty-three-tet.github.io/anima/

2 Literature Review

We first survey work related to the computational modeling of music and cultural practices of microtonality.

2.1 Computational Analysis of Harmony and Tonal Structures

Computational analysis of harmony and tonal structures is informed by advances in both cognitive and neo-Riemannian approaches. Balzano [6] frames harmonic structures using cyclic groups, enabling intuitive explorations of 12-tone and microtonal systems. The Harmony Space interface [1], introduced by Holland (1994) [17], is a pioneering interactive system for exploring and learning tonal harmony. Drawing on Balzano's and Longuet-Higgins' theories, it employs a unique spatial metaphor to make complex harmonic concepts accessible to novices while providing advanced tools for experienced musicians.

Furthermore, as seen in chord complexes, topological structures extend this analysis by visualizing harmonic trajectories in multi-dimensional spaces, providing deeper insights into the relationships between chords, particularly in modern music analysis and classification tasks [8]. Chew [10] proposes a Spiral-Array model representing tonal relationships through an interior-point approach in three-dimensional space, where higher-level musical structures (chords, keys) are modeled as convex combinations of lower-level components within a spiral derived from the Harmonic Network (Tonnetz). This continuous representation, validated through geometric mappings to Lerdahl's tonal pitch space [20] and Krumhansl's [19] experimental findings, transforms traditionally combinatorial music analysis problems

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into computationally efficient nearest-neighbor searches while maintaining structural consistency with established music theory. These approaches offer valuable insights into methods for modeling, analyzing, and teaching harmony in computational and educational contexts, concluding that exploring microtonality could open up new, untapped avenues for deeper harmonic exploration.

2.2 Cultural Practices of Microtonal Music

Microtonal music has been implemented across diverse cultural practices and artistic projects. Harry Partch's pioneering work with Greek scales led to his construction of 43-tone scale instruments for his compositions [14]. Contemporary microtonal music has found a significant platform through online platforms, with dedicated content creators such as Hear Between The Lines [21], Zheanna Erose [11], Mike Battaglia [7], and Maddie Ashman [5]. Award-winning musician Jacob Collier incorporates microtonal chords into contemporary Western popular music. The growing interest in microtonal music has influenced instrument development, exemplified by the *Lumatone* [18]. While this instrument represents an advancement in microtonal performance capabilities, its high cost is a barrier for musicians and researchers. The use of 53-TET extends beyond Western music, serving as the standard tuning system in Turkish maqam music [29]. The *xenharmonic* [28] music movement, particularly within electronic dance music, has fostered a community of artists exploring alternative tuning systems, including notable contributions from Elaine Walker, Birdhouse, and Stephen James Taylor [27].

2.3 Microtonality In Computer Music Modeling

Anders and Miranda [4] developed a computational model for microtonal music theory and composition using constraint programming implemented in the now-discontinued *Strasheela* music composition system [3]. This model supported various temperaments and allowed composers to define constraints for shaping microtonal compositions across harmony, melody, and counterpoint, applying Western music theory concepts to microtonal contexts. Chadwin [9] explored microtonality in popular music and demonstrated that microtonal techniques can be effectively integrated into contemporary songwriting across pop, rock, and electronic genres, which expands the creative palette for songwriters. Hirai et al. [15] introduced a microtonal music dataset of 100 music pieces with .wav and MIDI files with various tunings, offering machine learning and MIR research support. These studies underscore the growing interest in microtonality and the need for new theoretical frameworks and tools to explore microtonal systems in modern music practice.

3 Musical Context and Notations in 53-TET

3.1 Why 53-TET?

The 53-tone equal temperament (53-TET) stands out for its close approximation of intervals found in just intonation [23], a tuning system in which simple whole-number ratios define intervals. For example, the perfect fifth is the interval where the higher note's frequency is 3/2 that of the lower note, yielding a naturally consonant sound. As noted by Holder [16], if the commas are made equal, the octave can be divided into 5 whole tones and 2 diatonic semitones, with each step—known as a Holdrian Comma (HC)—representing approximately 22.6415 cents [26]. Similarly, Jing Fang (78–37 BCE) observed that stacking 53 perfect fifths (each with the 3:2 ratio) nearly equals 31 octaves [22]. 53-TET approximates both Pythagorean and just intonation intervals by "tempering out" two small intervals: the *schisma* (32805/32768, approximately 1.95 cents) and the *kleisma* (15625/15552, approximately 1.97 cents), effectively treating them as unison.

3.2 Equal Temperament Calculation

The methodology to calculate the tempered pitches employs an information-based approach that extends modern harmony principles into finer divisions, relying on mathematical precision to develop the computational tool. The resolution of temperament is achieved by identifying approximate common divisors of irrational numbers that correspond to musical intervals, a process referred to as **antanáiresis** [12]. This approach is mathematically expressed as: cents = $1200 \times \log_2(\text{ratio})$ Here, the octave is divided into 1200 cents, with the perfect fifth represented by the ratio 3 : 2, which calculates to: **701.9550008653874** cents. Different tempered scales approximate this interval with varying levels of precision. The successive approximations of their relation are shown in Table 1. The 1200-cent quantization of the octave is then multiplied by a ratio to establish the location of the fifth interval. This table shows different ratios used to approximate the perfect fifth in various temperaments. The 7:12 ratio represents a slightly detuned fifth in 12-TET, while 31:53 demonstrates why 53-TET provides an excellent compromise between accuracy and practical implementation with fewer than 100 divisions of the octave.

Cents	Ratio	P. 5th Approx.
1200 x	3 : 5	720.00
1200 x	7 : 12	700.00
1200 x	24 : 41	702.43902
1200 x	31 : 53	701.88679
1200 x	179 : 306	701.96078

Table 1: The perfect fifth approximations in tempered tunings.

3.3 Harmonic Exploration, Modes, and Notations

The central concept of this work is to facilitate harmonic exploration by focusing on modal logic and chord construction by stacking thirds and using substitutions or alterations. Although it is not a technical limitation, in this paper, we limit our scope to heptatonic modes for simplicity of formalism and to maintain clarity and accessibility when extending to 53-TET. We thus retain the naming conventions of modes from modern Western music theory.

While 53-TET contains the minor and major thirds of 12-TET, it introduces other thirds that create new modal colors and chord qualities. We can first consider 31-TET, in which appear *subminor*, *neutral*, and *supermajor* thirds, adding gradations between the usual minor and major thirds. 53-TET takes this gradation even further by introducing more intervallic qualities, such as *downminor*, *neutral minor*, or *upmajor* (respectively annotated `vm`, `^^m`, and `^M`). The complete list of interval qualities and their notations is shown in Table 2.

Once a mode is established, chords can be constructed by stacking thirds. Substitutions, alterations, and inversions can enrich

n-TET	Qualities
12	*minor* (m), *major* (M)
31	*subminor* (sm), *minor* (m), *neutral* (N), *major* (M), *supermajor* (SM)
53	*subminor* (vvm), *downminor* (vm), *minor* (m), *upminor* (^m), *superminor/neutral minor* (^^m), *submajor/neutral major* (vvM), *downmajor* (vM), *major* (M), *upmajor* (^M), *supermajor* (^^M),

Table 2: List of possible qualities for a third, seventh, ninth, and thirteenth chord intervals, and their notation.

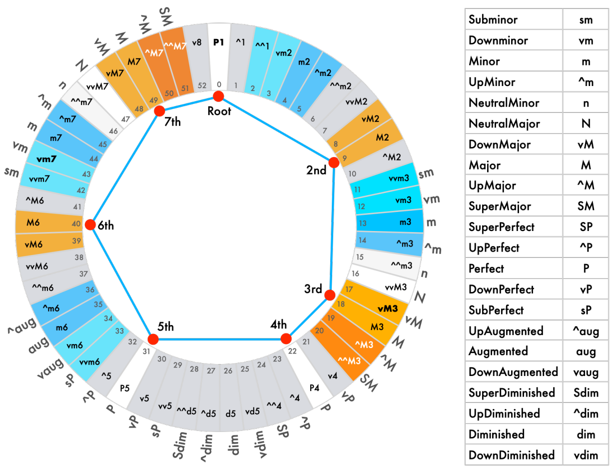

Figure 1: Scale distances defining the chord qualities

the harmonic possibilities and improve voice leading in chord progressions. Because of the new chord qualities available in 53-TET, we need to use a new notation to express the range of chord quality. Figure 1 shows the different qualities and notations for the different elements in a chord. The notation system for chords follows the same syntax as jazz notation, where intervals are explicitly indicated: the root is followed by the third quality, the seventh, and then potential extension or alteration. For instance, the chord with a root of vD, a *neutral minor* third, and a *subminor* seventh, is annotated:

$$\left.\begin{array}{rl} \text{root:} & \texttt{vD} \\ \text{third:} & \text{neutral minor (n)} \\ \text{fifth:} & \text{perfect} \\ \text{seventh:} & \text{subminor (sm)} \end{array}\right\} \quad \texttt{vDnsm7}.$$

This notation format clearly expresses the chord content.

The new chord qualities provided by 53-TET significantly enrich harmonic possibilities. Even when keeping a perfect fifth, 100 possible combinations of the third and seventh exist, leading to new harmonic colors. For example, starting from a dominant chord featuring a major third and a minor seventh, modifying the seventh towards a more neutral quality such as *neutral minor* aligns the chord with the initial tones of the harmonic series. This stabilization alters its conventional dominant functional role expected in modern Western music theory. Hence, this transformation of stable, subdominant, or dominant chords creates more precise colors and new functional relations.

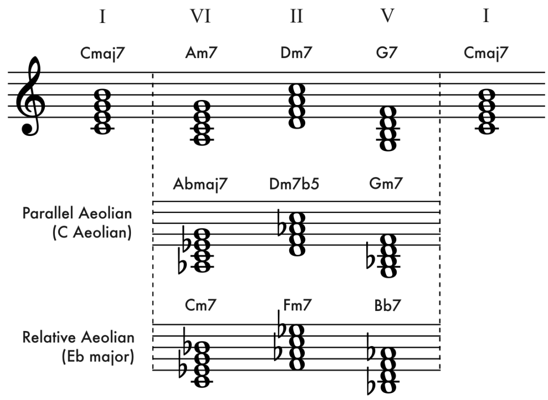

Figure 2: Example of modal interchanges in 12-TET

3.4 Modal Interchanges

Although harmonic exploration can be made through singular modes, a compelling method for expanding research to other chords is through modal interchanges. Modal interchange involves borrowing chords from parallel or relative modes to introduce new harmonic colors while maintaining a connection to the original mode.

Parallel Interchange: This involves borrowing chords from a mode sharing the same root as the original one. For instance, if we are in C major/Ionian, we can borrow from C Aeolian.

Relative Interchange: This involves shifting to a mode where the original root functions as a different degree of the scale and borrowing chords from the obtained mode. For instance, starting from C major/Ionian, an Aeolian relative modal interchange would place C at the 6th degree of E♭ major/Ionian. Therefore, we can borrow from E♭ major.

The distinction between parallel and relative modal interchanges appears more clearly when applied to chord progressions. Figure 2 shows a simple "`I vi ii V I`" 12-TET progression in C major, and the parallel and relative Aeolian interchanges for the middle chords. The move from Ionian to Aeolian means adding a ♭3 (E♭), ♭6 (A♭), and ♭7 (B♭). In the parallel interchange, the chords are still based on the root of C. Am7 becomes A♭maj7 to correspond to the new bag of notes of C Aeolian. Similarly, we obtain Dm7♭5 and Gm7. In the relative interchange, the chords are now based on the root of E♭. The `vi` is, therefore, the 6th degree of E♭ major, ie. Cm7. Similarly, we obtain Fm7 and B♭7.

This concept of modal interchanges can be directly applied to the extended modal possibilities of 53-TET. Once a mode is defined, parallel and relative motion can borrow new chords and harmonic content into a progression. This approach is at the core of harmonic exploration in our application.

4 Software Design

The software design is a two-tier system. It begins with ***The Bridge***, a *MaxForLive* [2] patch programmed in Max 8 (version 8.6.5) that connects the application to MIDI by translating 53-TET note coordinates into a 12-TET piano roll. MIDI polyphonic expression (MPE) [24] adjusts intermediate pitches precisely using pitch bend parameters. Unlike traditional MIDI, MPE assigns each note its own channel, enabling independent control of pitch, timbre, pressure, and volume per note, allowing digital instruments to respond more expressively. In Ableton Live (tested on

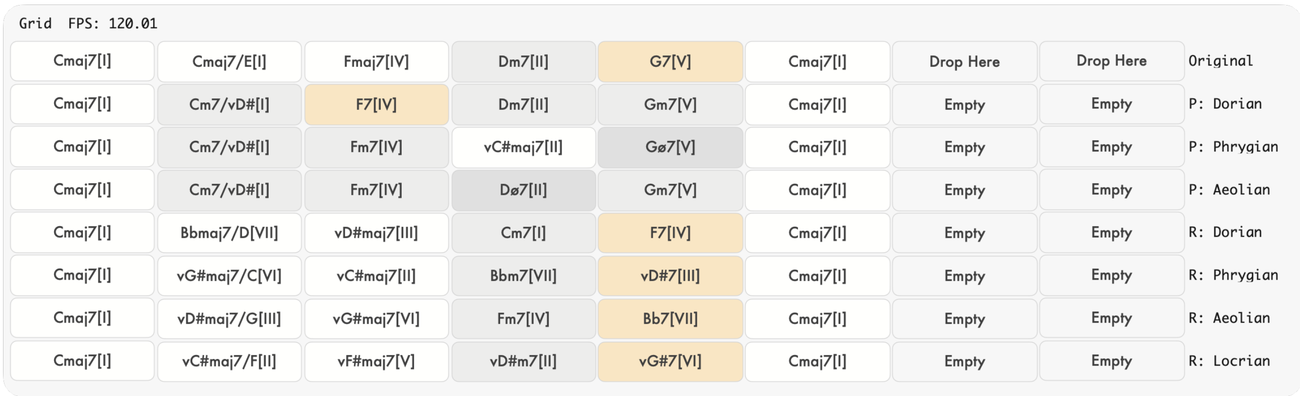

Figure 3: The Grid Scene: Modal Interchange in 53-TET

Live 11 and 12), this patch functions as a MIDI effect on any track, sending data to another track containing a *Wavetable* synth or any MPE-compatible instrument.

The second section is an interface visualization that contains a Scale Editor to adjust the interval distances, select the root, and the inversion of the chords. It includes a voicing visualization and editor to change the voicing parameters of the chords. An 8x8 grid with empty first-row slots, where chords can be dragged to compose chord progression; the other seven rows are modal interchange substitutions of the original chord progression, allowing listening, testing, and exploring harmonic possibilities of musical ideas in microtonality. It is programmed in OpenFrameworks version 0.12.0_Nighlty on Mac Sonoma 14.5.

4.1 The Bridge

Some DAWs can now map a MIDI piano roll into other temperaments. That is an easy solution for initial explorations, but it reduces the pitch range, as the limit of 128 keys is now mapped to a more detailed resolution. For example, 53-TET ends with only 2 octaves and some extra notes; if we start from A0, it reaches D2 minus 1 HC.

Therefore, we resolved this issue by still using the standard 12-TET range but adjusting the pitches implementing MPE. A *MaxForLive* patch receives an Open Sound Control (OSC) message with an array of a tuple with 53-TET notes and velocity. It is processed by a [poly~] object with 15 voices.

The [poly~] object converts 53-TET notes to standard MIDI/MPE by treating each step in 53-TET as a shift in frequency, with an offset frequency $K = 55.18012\,\text{Hz}$. This offset aligns 0 HC to the MIDI note $A1$ and 13 HC to $C2$. The reference frequency f for a given scale degree n is calculated as:

$$f = 2^{n/53} \cdot K$$

The reference frequency f is then translated to MIDI using the following formula:

$$m = 69 + 12\log_2(f/440)$$

The mapped reference in MPE is defined as:

$$\text{MPE} = (\lfloor m \rfloor, m \mod 1)$$

Here, $\lfloor m \rfloor$ represents the floor function corresponding to the *MIDI_note*. The $m \mod 1$ represents the fractional part used by the *pitchBend*. If pitchBend = 1, it is added to the *MIDI_note*, and its value is flattened to pitchBend = 0.

This method enables arrays of the tuple (53-TET, Velocity) chords to be mapped onto any DAW platform without losing the full spectrum of frequencies.

4.2 Interface Design

The scenes of the computer application are:

The Grid Scene consists of an 8×8 grid with free slots designed for experimenting with chord progressions and modal interchange substitutions, as shown in Fig. 3. It features:

- **A drag-and-drop chord list**: It is formed with the Ionian modes, starting with its seven chords (Cmaj7, Dm7, Em7, Fmaj7, G7, Am7, and Bø7), and all those chords can be placed in the grid's first row to compose a chord progression.
- **A Scale Editor:** It allows the edition of notes contained in the main modal scale configuration in 53-TET, as shown in the visualization tool in Fig. 4. The exploration of different configurations starts with C Ionian as a reference. The interval names in 53-TET are shown, highlighting all relevant qualities available for 3rd, 5th, and 7th. For example, the harmonic 3rd and 7th are also marked. From the Scale Editor, it is possible to experiment with other configurations and intervallic distances such as subminor, downminor, minor, upminor, and neutral minor. The Scale Editor has an *inversion wheel* to configure other root dispositions of the chord, for example, Cmaj7/E. The internal wheel is used to choose any of the 53-TET available notes in the first three octaves to define the tonic of the available chords. All nodes can be dragged, and the internal wheels can be rotated.
- **A Voicing Editor:** We use the principle of the spiral visualization (zenithal view) of the disposition of the note per octave, based on Chew's method [10]. It is assigned by clicking on any chords available in the Grid. As shown in Fig. 5, the white notes are the active notes where the lower pitch starts in the smaller circle. A reference of the guide tones is shown in the reference wheels; each wheel is an *octave* upper from the root. The guide tones are shown in their related location of the 3rd, 5th, 7th, and extensions. The voicing is predefined concerning its function. However, a dynamic voicing checks for previous chords on its corresponding row and adapts the higher note to maintain an organic motion from chord to chord. The 9th is used as a pivot note that can be included to make chord transitions smoother.

The Modes Scene The second scene displays all modes transposed to the reference root, starting with standard Greek modes. While we retain their names as reference points, they become less applicable when scales are edited (see section 5.3). This scene

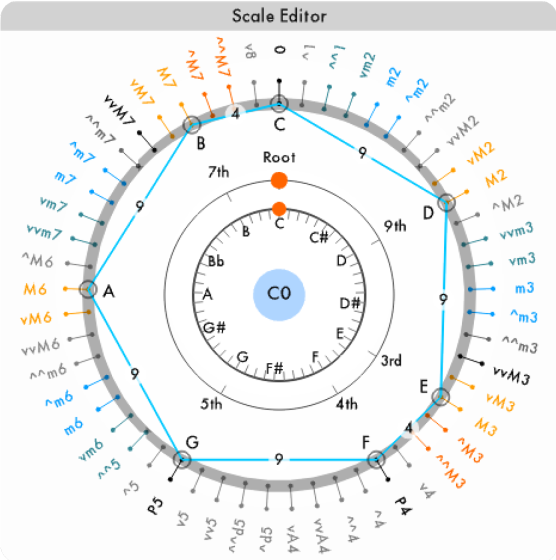

Figure 4: Scale Editor interface

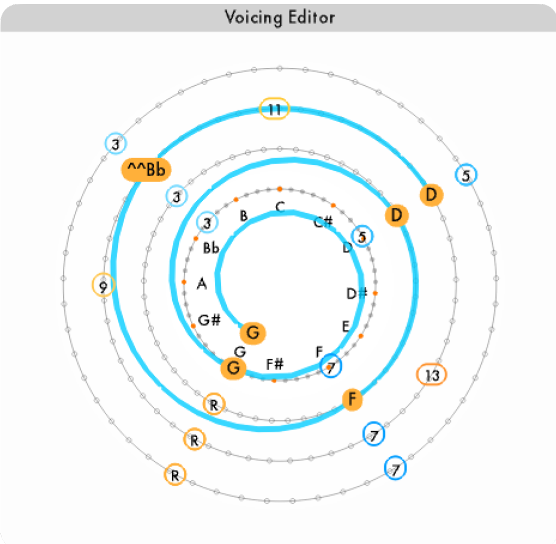

Figure 5: Voicing Editor interface

allows users to experiment with new scales and chord colors through clickable chords (Fig. 6). It features a list of seventh chords derived from each mode, all transposed to the root selected in the Scale Editor.

The Scales Scene The third scene contains the scales of all Greek modes transposed to the reference root, allowing the user to experiment with melodic constructions. As *Ableton Live* controls all sounds, recording this interaction in a MIDI track is also possible. All notes are clickable to trigger the sound. The Scene is shown in Fig. 7

The Lumatone Scene The fourth scene displays notes in the format of the *Lumatone* microtonal keyboard [18], allowing users to explore its key layout.

As an *Ableton Live* extension, all sounds are generated via MPE-compatible MIDI instruments, with played chords recordable as standard MIDI tracks editable through any DAW tool.

We integrated the Launchpad Pro [MK3] controller for real-time interaction, mapping its touch-sensitive triggers to the 8x8 interface grid. This grid is organized with the first row for original chord progression composition and seven rows below for modal interchange substitutions: parallel Dorian, Phrygian, and Aeolian, followed by relative Dorian, Phrygian, Aeolian, and Locrian (Fig.3). The Launchpad can also function as a keyboard for playing reference scales in other scenes.

5 Demo and Discussion

5.1 Modes Examples

In the **Modes Scene**, we have a disposition of all modes with their respective chords in a 7x8 matrix of clickable buttons. The Modes can be changed using the **Scale Editor** and the **Voicing Editor**.

The **Modes Scene** lets users experiment with different scale configurations, exploring microtonal harmonies by extending Western principles. Users create *modes* by dividing 53-TET into seven-note scales. The HC array $[0, 9, 9, 4, 9, 9, 9, 4]$ corresponds to 12-TET $[C, D, E, F, G, A, B, C]$, forming the Ionian mode `Cmaj7, Dm7, Em7, Fmaj7, G7, Am7, Bø7, Cmaj7`. Through the **Scale Editor**, users can explore various 53-TET subdivisions, generating new chord qualities and colors.

To discuss some basic examples of modes and new chord qualities, in Fig. 8, three configurations are shown:

- **Ionian Mode:** The first row shows the standard Ionian modal sequence of chord qualities and its corresponding array of HCs distances.
- **SubMinor Mode:** In the second row, we have an array of HCs distances $[0, 9, 3, 10, 9, 3, 10, 9]$ with chord degrees `Cvm7, Dø7, vvD#^m^m7, Fvmvm7, Gm7, vvG#^m^m7, BbMvm7`. The `Mvm7` chord exhibits dominant quality while aligning with the harmonic series, making standard 12-TET dominant sevenths sound misaligned by comparison. The `vm7` sounds like a well-tuned minor, and the `^M^M` provides a pleasing maj7 sonority.
- **Harmonic 3rd, and Harmonic 7th Mode:** The fourth row is formed by the HCs distances $[0, 9, 8, 5, 9, 8, 4, 10]$ and its chord formation `CvMvm7, Dm7, vEø^m7, FvMvM7, Gvm7, vA^m^m7, vBb^Mmaj7`. The `vMvm7` appears dominant-like but it is consonant with harmonically aligned intervals (5/4, 3/2, 7/4). `Dm7` functions conventionally, `vEø^m7` provides subdominant quality, `vMvM7` offers enhanced consonance, and `vm7` works as a traditional minor. `^m^m7` creates a distinctive consonant block sound with possible dominant function, while `^Mmaj7` is less stable than maj7 or `vMvM`.

5.2 Examples of Modal Interchanges

The Modal Interchange navigation is done in the **Grid Scene**. This scene allows the user to drag and drop chords from a list of seventh chords formed out of the current configuration of the **Scale Editor**. These chords are placed in the first row, and the Modal Interchange occurs automatically. For practical demonstration, we've implemented several 53-TET modal interchange examples in our application. Hear these chord progressions at our project website.[1]

[1]https://fifty-three-tet.github.io/anima/

Chords FPS: 137.76

Cmaj7[I]	Dm7[II]	Em7[III]	Fmaj7[IV]	GMm7[V]	Am7[VI]	Bø7[VII]	- Ionian
Cm7[I]	Dm7[II]	vD#maj7[III]	FMm7[VI]	Gm7[V]	Aø7[VI]	Bbmaj7[VII]	- Dorian
Cm7[I]	vC#maj7[II]	vD#Mm7[III]	Fm7[VI]	Gø7[V]	vG#maj7[VI]	Bbm7[VII]	- Phrygian
Cmaj7[I]	DMm7[II]	Em7[III]	F#ø7[VI]	Gmaj7[V]	Am7[VI]	Bm7[VII]	- Lydian
CMm7[I]	Dm7[II]	Eø7[III]	Fmaj7[VI]	Gm7[V]	Am7[VI]	Bbmaj7[VII]	- Mixolydian
Cm7[I]	Dø7[II]	vD#maj7[III]	Fm7[IV]	Gm7[V]	vG#maj7[VI]	BbMm7[VII]	- Aeolian
Cø7[I]	vC#maj7[II]	vD#m7[III]	Fm7[IV]	vF#maj7[V]	vG#Mm7[VI]	Bbm7[VII]	- Locrian

Figure 6: Modes Scene

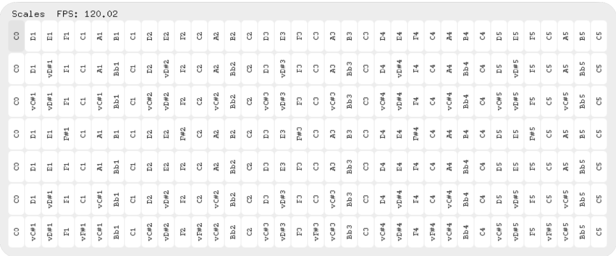

Figure 7: Scale Scene

CvMvm7[I]	FvMvM7[IV]	Dm7[II]	Gvm7[V]	CvMvm7[I]	Original
CvMvm7[I]	Fvm7[IV]	vDø^m7[II]	vG^m^m7[V]	CvMvm7[I]	P: Dorian
CvMvm7[I]	F^m^m7[IV]	C#vMvM7[II]	vF#^Mmaj7[V]	CvMvm7[I]	P: Phrygian
CvMvm7[I]	^Fm7[IV]	vC#^Mmaj7[II]	Gø^m7[V]	CvMvm7[I]	P: Aeolian
CvMvm7[I]	vD#vMvM7[III]	Cm7[I]	Fvm7[IV]	CvMvm7[I]	R: Dorian
CvMvm7[I]	C#vMvM7[II]	^Bbm7[VII]	D#vm7[III]	CvMvm7[I]	R: Phrygian
CvMvm7[I]	G#vMvM7[VI]	^Fm7[IV]	^Bbvm7[VII]	CvMvm7[I]	R: Aeolian
CvMvm7[I]	^GvMvM7[V]	^Em7[III]	^Avm7[VI]	CvMvm7[I]	R: Locrian

Figure 9: Modal interchange in vMvM7

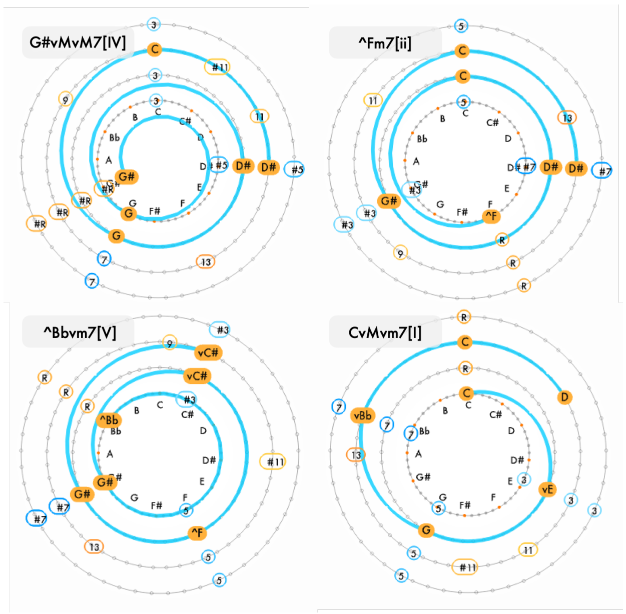

Figure 10: Voicing Aeolian relative substitution

In Fig. 9, we show the functional chord progression "`I, IV, ii, V, I`" using harmonic 3rd and 7th chords, expressed as `CvMvm7[I], FvMvM7[IV], Dm7[II], Gvm7[V], CvMvm7[I]`. The second row shows Dorian parallel substitutions: `CvMvm7[I], Fvm7[IV], vDø^m7[II], vG^m^m7[V], CvMvm7[I]`. The third row's Phrygian substitution features notable voice movement from `F^m^m7[IV]` (leading voice D#) to `C#vMvM7[II]` (D# becomes 9th), to `vF#^Mmaj7[V]` (leading voice moves to C#, the 5th), resolving to D (9th) in `CvMvm7[I]`. Row 7 shows Relative Aeolian substitution (Fig. 10) with `CvMvm7[I]` in the last quadrant (without 9th), and root `vEbvMvm7[I]`. Voice movement from `G#MvM7[IV] (G#, C, D# G)` to `^Fm7[ii] (^F, G#, C, D#)` transforms D# from 5th to 7th, then to `^Bbvm7[V] (^Bb, vC#, ^F, G#)`, where leading voice C# resolves to D (9th) in `CvMvm7[I]`.

As an observation, these harmonic motions demonstrate that standard Western modal interchange principles remain structurally sound in 53-TET while offering greater precision. The microtonal system allows for specific chord qualities like `vMvm7` and `^m^m7` that maintain their functional roles within progressions while providing more accurate representations of intervallic relationships aligning closer to the harmonic series. This higher resolution system extends rather than replaces traditional harmonic practices.

5.3 Conclusion and Future Work

We've developed a computer application for exploring microtonal harmony, featuring real-time chord exploration, interactive visualization, and MIDI controller support. Our approach extends modern harmonic principles into 53-tone equal temperament, expanding traditional tonality with modal interchanges, parallel chord substitutions, and microtonal intervals to reveal new harmonic relationships. Our implementation connects standard MIDI with microtonal control through a custom MaxForLive "The Bridge" and OpenFrameworks interface, demonstrating how established theories can adapt to extended tuning systems. This work provides both theoretical foundations and practical tools for composers to access a broader spectrum of musical expression.

Future work will focus on evaluating and enhancing the developed application. First, qualitative studies will be conducted with relevant artists in the field in order to gather feedback and inform further improvements.

We aim to define new functions and advance microtonality in music theory by automating the generation of wav sound files containing all possible chords, as detailed in Section 3.3. Each chord file, annotated with a corresponding JSON file specifying

HCs	Root	2nd	3rd	4th	5th	6th	7th
Major	Cmaj7	Dm7	Em7	Fmaj7	G7	Am7	Bø7
	0	9	9	4	9	9	9
SubMinor	Cvm7	Dø7	vvD#^m^m7	Fvmvm7	Gm7	vvG#^m^m7	BbMvm7
	0	9	3	10	9	3	10
H_3rd H_7th	CvMvm7	Dm7	vEø^m7	FvMvM7	Gvm7	vA^m^m7	vBb^Mmaj7
	0	9	8	5	9	8	5

Figure 8: Scale comparison with related chords

chord name and voicing, will support supervised learning algorithms to classify chords by harmonic properties. Specifically, we'll analyze chord consonance and dissonance relative to the harmonic series and apply Music Information Retrieval tools to extract audio descriptor features. Dimensionality reduction techniques (PCA, t-SNE) and variational autoencoders will create a meaningful lower-dimensional representation, enabling clustering algorithms (k-means, hierarchical clustering, GMM) to group chords by harmonic similarity. This approach will reveal clear patterns in chord qualities for further combinatorial exploration.

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7 Ethical Standards

This work adheres to accepted principles of ethical and professional conduct, ensuring transparency and objectivity throughout. No data was collected from users; thus, informed consent and welfare statements are not applicable to this research. Additionally, there are no conflicts of interest, financial or otherwise, to disclose.

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