Interactive music system based on pitch quantization and tonal navigation

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Abstract

Recent developments in the field of human computer interaction have led to new ways of making music using digital instruments. The new set of sensors available in devices such as smartphones and touch tablets propose an interesting challenge in the field of music technology regarding how they can be used in a meaningful and musical way. One to one control over parameters such as pitch, timbre and amplitude is no longer required thus making possible to play music at a different level of abstraction.

Lerdahl and Jackendoff presented in their publication "Generative theory of tonal music" a perspective that combines Heinrich Schenker's theory of music and Noam Chomsky linguistics to explain how tonal music is organized and structured. This idea opens up the possibility of investigating ways to manipulate a "wider" aspect of music through an assisted interactive musical system that takes into account the "principles" or common knowledge used in music composition and performance. Numerous publications exist in the field of music theory regarding how the tonal aspect of music works. Due to aspects related to psychoacoustics and cultural inheritance, there is a certain common base on how to form and use chords and scales, and how they are organized in terms of hierarchies, movement tendencies and tonal functions.

This project deals with the design of a graphical representation about the use of tonality in jazz and popular music, organizing chords and scales in a hierarchical, semanticall and practical way. This representation, which we call "Tonal map", is then used as the graphical interface of an interactive system to manipulate different data types in real-time. The process consists in adjusting note values (pitches) using a set of rules that characterize each sector of the graphical representation. The output produced by system is the "tonally quantized" version of the input data using as transformation parameter the set of rules that the user chooses through the graphical interface.

The graphical model was constructed using different methods for learning modern harmony and taking also into account models of music perception and cognition. The interactive system was implemented through a Max for Live patch that works as a MIDI effect. Input data is first transform into MIDI note events that are modified according to the users selection in the tonal map. The hardware interface uses a Wacom tablet with a printed version of the tonal map. The interaction can be seen as a tonality selector for real time transformations of MIDI data. The prototype can also be used with several inputs at the same time allowing collaborative playing.

Acknowledgments

First, I will like to thank my family for their constant and generous support with their positive energy and enthusiasm. I will also like to thank my friends from the Master program who have made this time in Barcelona amazing, through all the academic and non academic experiences we shared.

Finally I will like to thank all the teachers from the Master Program for sharing their knowledge and for helping me learn and enjoy the process.

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1. Introduction

1.1 Motivation. What could be better?

The primary motivation of this project is to create a tool for understanding how tonal harmony works. Afterwards we will implement an interactive system that incorporates this knowledge to create new ways of performing music, using higher-level descriptors of harmony.

The study of harmony usually takes several years and often it is not taught in an orderly and unified way, but rather as a series of independent concepts without a clear logical relationship between them. The creation of a graphical representation could be useful to structure this knowledge.

Regarding interactive composition and electronic music performance, there is much progress in the field of gesture acquisition, but there are still difficulties to map these inputs in meaningful ways. In my opinion, transformations of music control data (such as MIDI or OSC), have not been fully explored. Many digital instruments are still using traditional paradigms (such as one-to-one control) and few tools for dealing with the tonality are available. Most of the actual systems are based on drop down menus to access harmony related information (chords, scales, transformations, etc.) and this limits the creative flow in music creation.

1.2 Orientation.

The approach is to create a MIDI filter that quantizes pitch. The inputs of the system are MIDI notes generated from different gesture sources (electronic drum sets, Wii controllers, iPhones, sensors, etc.). Afterwards the filter works as a chord and scale palette where the user chooses which tonal elements to use in the performance. The outputs are events produced by gesture that are tonally quantized.

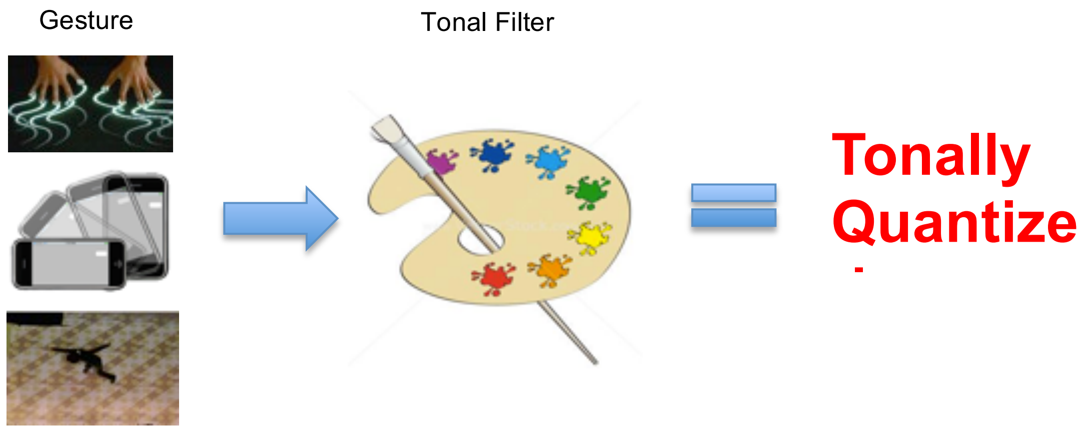


Illustration 1. General concept for the design of the interactive system. Gesture + Filter + Tonally quantized gesture

The knowledge included in this interactive system for assisted tonal navigation comes from music cognition studies, classical harmony and Jazz harmony. The knowledge is presented through a graphical representation that starts as a bidimensional space but can be expanded through different layers added to the system.

The use of a graphical representation has been chosen based on its efficiency to help in visualizing structure and taxonomy of abstract ideas.

Effect of Various Instructional Modes on Learning (Hannum)

Mode of Instruction	Effect Size in StdDev Units
Mastery Learning	0.50
Cooperative Learning	0.73
Frequent Testing	0.48
1:1 Tutoring	2.00
Generative Activities	1.15
Analogies	1.65
Comparison	1.32
Note Taking	0.99
Homework	0.77
Advance Organization	0.48
Graphic Representation	**1.24 (higher for abstract ideas)**
Goal Specification	0.97
Summarizing	1.00
Asking Questions	0.93

Illustration 2. Effect of various instructional modes on learning (Hannum)

1.3 Like a steal pedal guitar?

The pedal steel guitar is the most important reference among traditional instruments because it implements very similar concepts. Performers change the behavior (Tuning) of the instruments by pressing different pedals that modify the type of chord that is being produced. The slide used in the neck of the instrument works similar to the transpose MIDI controller in the sense that it represents an offset applied to the chord structure. Other pedals (and knee levers) are used to modify the chord predefined by the tuning system. Because of the instrument's tuning system, one could assume that the instrument has some built-in knowledge and afterwards the user performs by morphing these predefined values with the pedals. The function of the pedals can be customized for each user.

Illustration 3. Steel pedal guitar; an existing instrument using a similar approach.

Performing at different levels of abstraction?

One of the motivations behind this project is to create an instrument that helps to segregate different levels of abstraction in music performance. Traditional instruments tend to use the one-to-one control paradigm, which has some clear advantages for expert performers but also makes it difficult to explore other layers of musical abstraction. An electronic instrument could take advantage of its capabilities to remember and make decisions [1] and to assume some tasks of micro control during the performance allowing the user to focus on different aspects of music. In this project we seek to create a system that allows for the exploration of tonal concepts of music by taking advantage of the computer's ability to store and process musical knowledge.

2. Music Background

Although defined in many ways, music is essentially the art of ordering sounds with the intent to communicate an idea or emotion to the listener. Harmony, in the context of music theory, is responsible for studying the relationships of simultaneous sounds, describing and prioritizing them and defining the roles that are developed in a tonal system. Although these possibilities are endless, there are certain psychoacoustic phenomena that suggest the existence of a sort of musical grammar. [2]

2.1 Brief History of Tonality

Tonality is a system where the pitch classes are organized hierarchically based on their relationships with a key center or tonic. The term was introduced by Alexandre-Étienne Choron in 1810 but the idea was developed through the compositions of the so-called common practice period between 1600 and 1900 (Baroque, Romanticism and Classical). From the concept of tonality derives the ideas of consonance and dissonance, which are considered tightly related to the relaxation and tension patterns in music.

The first tonal theory of music was made by Jean-Philippe Rameau in his Treatise on Harmony in 1722 [22] in which he organized pitch relationships according to acoustical principles. In his treatise he proposed the names for the primary chords (tonic, subdominant and dominant) and also discussed the idea of chord inversions. From that time, chords were traced back to their initial position: root position.

In the19th century Fetes (1844) described harmony as *"set of relationships, simultaneous or successive, among the tones of the scale"* and also supported the idea that tonality was a cultural phenomena *"For the elements of music, nature provides nothing but a multitude of tones differing in pitch, duration, and intensity by the greater or least degree... The conception of the relationships that exist among them is awakened in the intellect, and, by the action of sensitivity on the one hand, and will on the other, the mind coordinates the tones into different series, each of which corresponds to a particular class of emotions, sentiments, and ideas. Hence these series become various types of tonalities"* [23]. In the other hand theorists Hugo Riemann thought that the affinity among tones was a completely natural phenomena. Riemann set the basis for functional harmony by analyzing chords progressions and tendencies. As a result he organized the diatonic chords into tonic, subdominant and dominant according to their stability. During the 19^{th} century more chromatic sounds started to be used together with four note chords, therefore expanding the possibilities of the use of harmony and the concept of tonality.
In the 20th century a more detailed description of tonal harmony was made by Arnold Schoenberg in his publication *Harmonielehre* (Theory of Harmony). Schoenberg the construction of chords, scales, and chord progressions, mostly based on the idea of tonal distance. Additionally Heinrich Schenker added the notions of horizontal relationships in which he proposed that every successful

tonal piece is based on a simple cadence, which is then elaborated and elongated in the middle and foreground. Schenker used graphical methods to support his analysis.

2.2 Jazz Harmony

Jazz started in the beginning of the 20th century as the confluence of African and European music styles. During the Atlantic Slave Trade, many Africans were brought to the United States and with them came many musical traditions. African music was mainly based on the predominance of melody and dance, which imply accuracy and variety of rhythm. Western music was more developed in terms if harmony [27]. After the abolition of slavery many black people receive access to musical education and started to learn to play European instruments. Their appearance in the entertainment sector mostly in minstrel shows made this genre very popular.

Because of the many sub styles that are included in Jazz, it is difficult to make a definition that includes them all but, as stated by Travis Jackson, jazz is a music that includes swinging, improvising, group interaction, developing an individual voice, and being open to different musical possibilities. [26] This definition is especially interesting in the conceptual development of our instrument since one of our ideas is to bring this type of musical interaction to new digital instruments.

There has always being an exchange between Jazz and traditional music, making possible to blend different styles, with their characteristic rhythmic and harmonic elements. Jazz has evolved into a large amount of subgenres that have their own stylistic characteristics, but in general there are some common harmonic choices that define the style such as the use of tensions and seventh chords. Most of these tonal harmony concepts will be mentioned in the section 5.1 called "Music theory to be included".

2.3 Graphical representations of tonality

Graphic representations of tonality are the core of this project since they will serve as the navigation map that will allow the user to explore tonality. In this section we will study different models that have being used in order to set the ground for the representation that we want to propose. The main questions that we will try to address are:

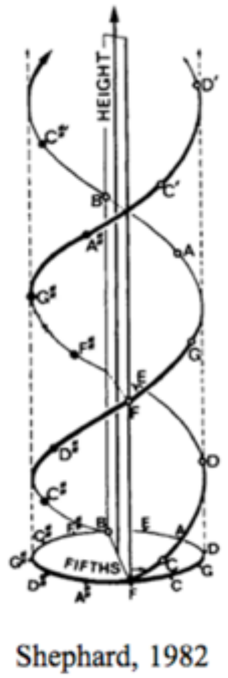
- Is it possible to use a graphical representation of tonality in the design of an interactive system?
- What type and how much information should be included?
- How should we propose a graphical hierarchy that is somehow related to musical hierarchy?

- Are there models that represent “distance” between tonal elements of music?

2.3.1 The Tonal Pitch Space

There are many studies in music perception and cognition that could guide us toward a better understanding of tonality. The models that will be presented in this section propose different distributions of tonal sounds based on perceived distances among them (degree of relatedness). Depending on the amount of dependencies that the representation might include, multidimensional maps could be required. The representations that are more related to the aim of this project are “The pitch Class Space”, the “Chordal Space” and the “Modulatory Space”.

2.3.2 Sheppard's helice



This representation proposed by Sheppard [28], explains the concept of Chroma (organization of pitches according to their type without making any distinctions regarding octaves). Each pitch class is represented through a vertical line that has the intercepts the helice in each octave.

Illustration 4. Helice of Sheppard

2.3.2 Circle of regions by Heinichen

The circle of regions of Heinichen (1728) shows the circle of fifths with the relative minor of each tonality. In this case the distance between consecutive elements is based on the amount of alterations that they have in their scales.

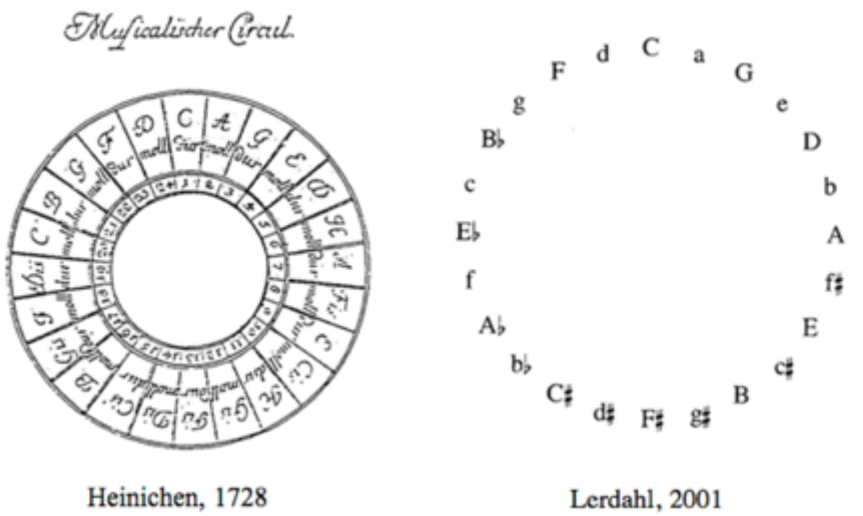


Illustration 5. Circle of regions by Heinichen

2.3.3 Circle of regions by Kellner

This is a similar representation but using concentric circles of Major and Minor scales. We find these "Concentric" circles of tonality modes very interesting since it would be easy and logical to navigate between the different modes (Intermodulation). In this case only the minor natural mode is used.

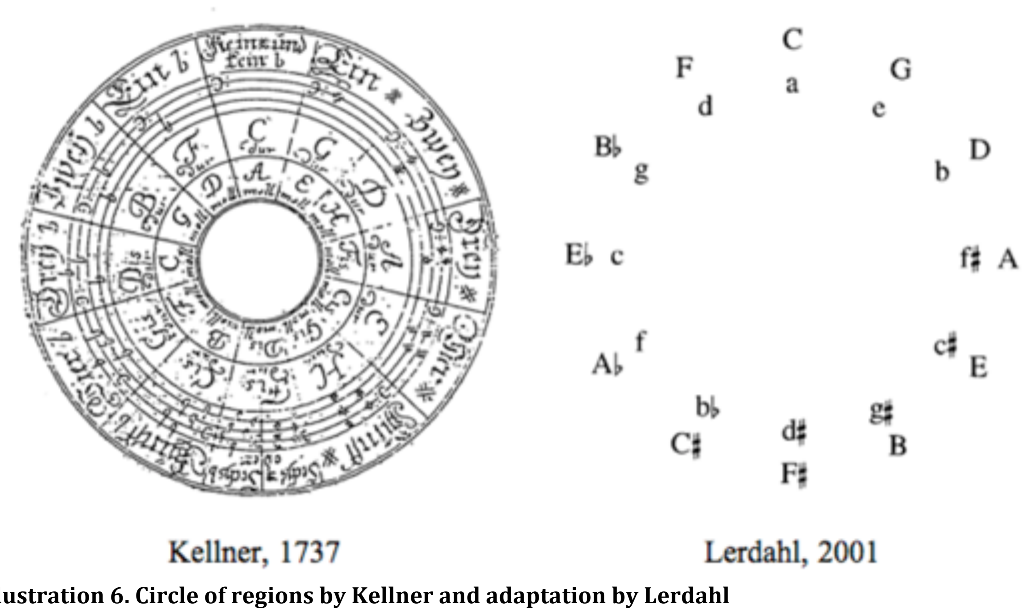


Illustration 6. Circle of regions by Kellner and adaptation by Lerdahl

2.3.4 Tonnentz of Hugo Riemann

Illustration 7. Tonnentz of Hugo Riemann

The tonnetz of Hugo Riemann added another dimension to the representation in order to include the relationship of tonalities by thirds in the vertical axis and the circle of fifths in the horizontal axis. In this representation only

2.3.5 Regions of Weber

Weber proposed a new representation, which included the minor natural mode. In this case the vertical axis contains movements by fifths, the horizontal axis by thirds and parallel modes (same tonic but in minor mode).

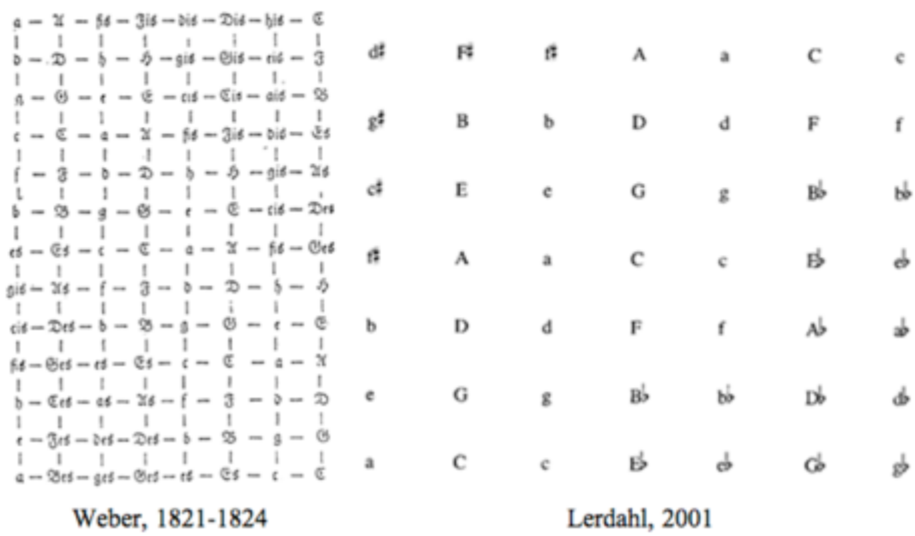


Illustration 8. Regions of Weber, adaptation by Lerdahl

2.3.6 Pitch Class Proximity of Krumhansl

The fallowing representation was the result of psychoacoustic measurements that were made by having subjects classify the perceived distances between pitch classes. Even though this might not be a practical representation for designing our interactive system, it is interesting to reflect about the possibility of a 3D representation of tonality.

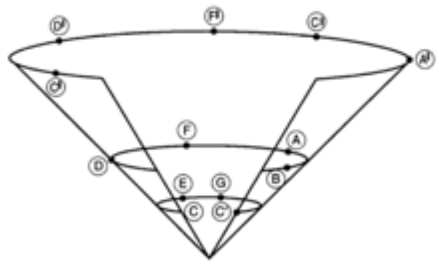


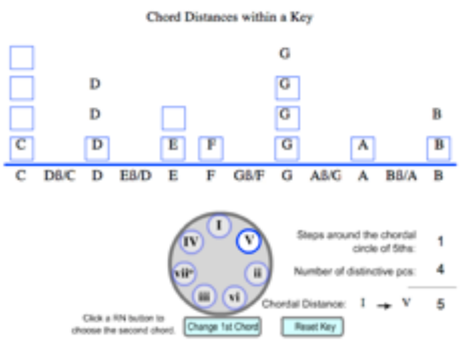
Illustration 9. Pitch class proximity by Krumhansl

Discussion about the mentioned models

The models mentioned above serve as the ground in the development of the tonal space theory. However, these models only imply a very broad aspect of tonality, which is the set of notes that each tonality uses, but not how they function internally in a practical and unified way. In the next section we will discuss other models that represent with more detail the tonal space.

2.3.6 Chord Space of Lerdahl

Lerdahl proposed a system to determine the distance between chords in a tonality. After calculating the distances to each possible chord he proposed the chord space that can bee thought as a toroidal structure showing all the chords formed in each degree of the major scale.



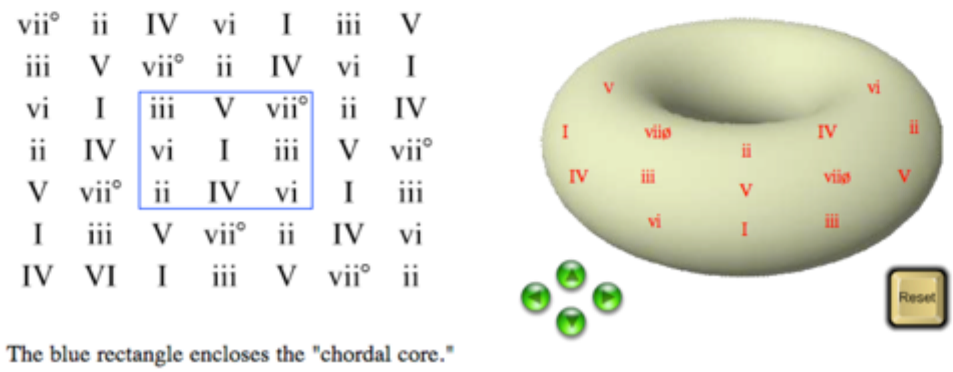


Illustration 10. Chord space of Lerdahl, toroidal structure

2.3.7 Combined Space of Chord and Regions of Lerdahl

Using a similar rule Lerdahl calculated the distance between regions and then combined the space of chords and the space of regions, producing the representation shown below.

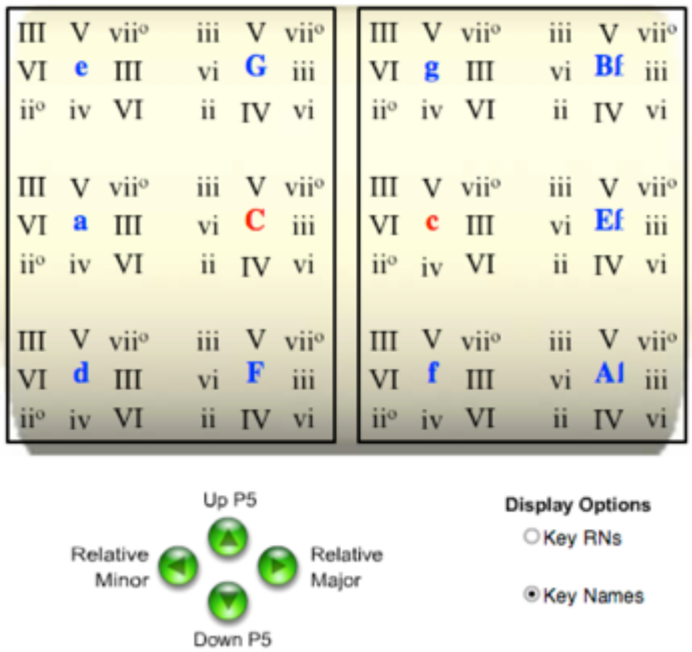


Illustration 11. Combined space of chord and regions by Lerdahl

This representation is very interesting because it includes both concepts in a single graphic (Regions and diatonic degrees). On the other hand the representation is limited in the sense that only considers triads chords, only two modes for each tonality (major and minor natural) and also it is difficult to visualize common chords to different tonalities.

A practical aspect of this representation is that it could be used to analyze musical pieces, as it is shown n the figure bellow.

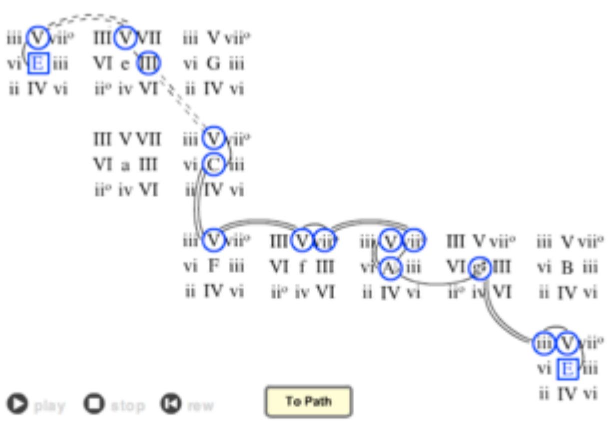


Illustration 12. Harmonic analysis using the combined space of chords and regions by Lerdahl

2.3.8 Chord Wheel

The chord Wheel is a graphical representation developed by Jim Fleser[1] that contains the regions displayed by circle of fifths and additionally the diatonic degrees. It consists of an image with the chord names and a transparent layer that rotates, to show more detail information about chord possibilities regarding their species (the specie of a chord represents its internal structure).

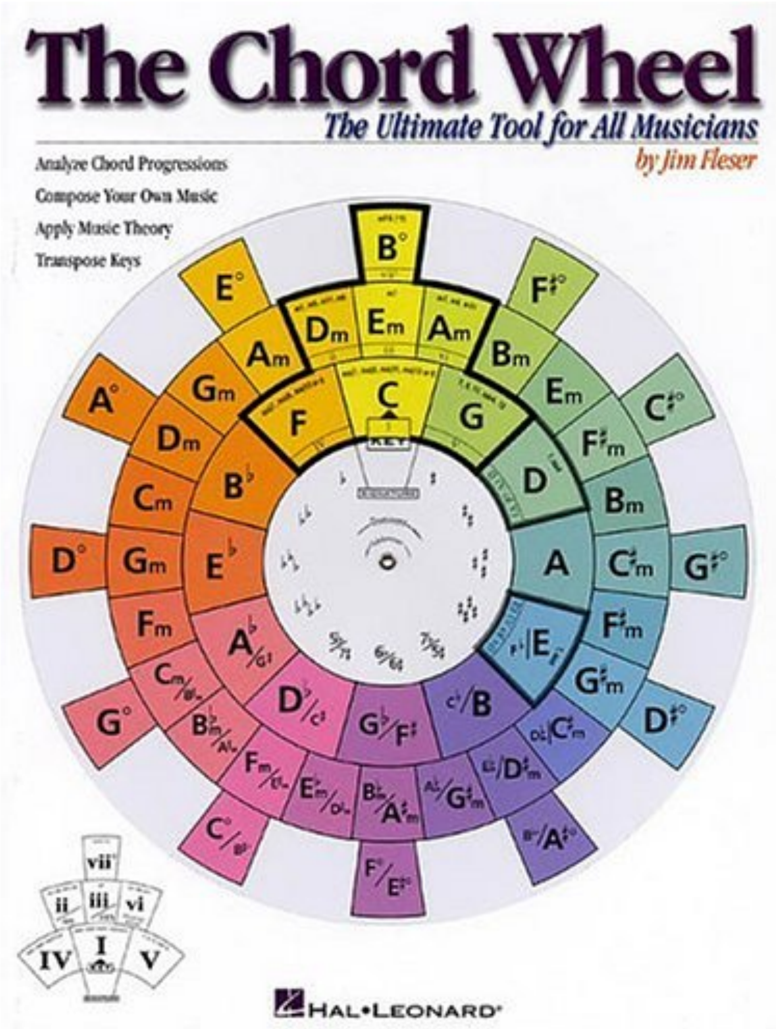


Illustration 13. The chord wheel by Jim Flesser

The main disadvantage about this system is that is limited to the Major mode (no other major and minor modes are shown). Some other aspects that this representation does not include are: substitute dominants, secondary dominants, II relatives, chord scales and some other music elements that we will mention on the section 5.1 called "Music theory to be included".

[1] http://www.chordwheel.com/

2.3.9 Harmonic wheel, Musical Abacus and Improchart

A Spanish engineer called Luis Nuño has developed some tools for learning and using concepts of tonal harmony similar to the ones we want to propose. From my point of view these tools are quite interesting in intention but the graphical representation and structure of information is not very clear and practical. According to Nuño "The technical study of this part (theory of tonality) usually takes several years and often its not taught in an orderly and unified way, but rather as a series of independent concepts without a clear logical relationship between them"[2].

Musical Abacus

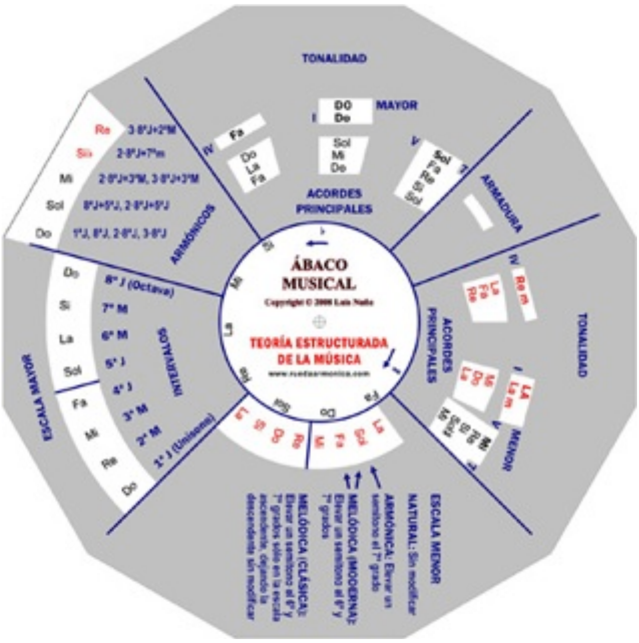


Illustration 14. Musical Abacus by Luis Nuño

Summary of contents[3]:

1. A **Major Key** and its **relative minor.**
2. The corresponding **Major Scale and its relative minor.**
3. The **Intervals** from the Tonic of the Major Scale.
4. The **3 Main Chords** in both Keys and their **Arpeggios.**
5. The **Harmonics** produced by the Tonic of the Major Key.
6. The corresponding **Key Signature** for both Keys.

Harmonic Wheel

[2] http://www.ruedaarmonica.com/
[3] http://www.harmonicwheel.com/musical-abacus.php

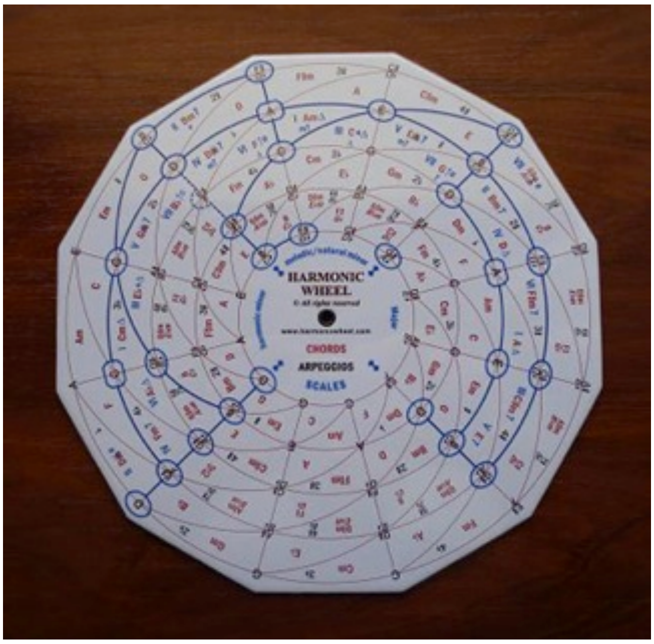


Illustration 15. Harmonic Wheel by Luis Nuño

Summary of contents[4]:

1. Enharmonic notes and chords
2. Given a note, obtaining the 6 notes with which it forms consonant intervals.
3. Obtaining the interval between any two notes.
4. Notes of every Major Scale.
5. Notes of every minor Scale (harmonic, melodic or natural).
6. Key Signature of any Major or minor Scale.
7. Map of the Keys: Cycle of Fifths and Changes of Mode.
8. Arpeggios of any Major or minor chord.
9. Given a note, obtaining the 6 consonant chords (Major and minor) containing it.
10. Arpeggios of any Augmented or diminished chord.
11. Simple graphical representation of all possible 3 and 4 note chords built by superimposing Major and minor thirds. Finding their arpeggios.
12. Chord Finder: Chords associated to any Major or minor scale (harmonic, melodic or natural).
13. Graphic visualization of the chords, which are more affine or less affine to a given scale.
14. Transposition of a chord progression.
15. Simple graphical representation of Pentatonic Scales and deriving their main properties.
16. Simple graphical representation of diminished and Hexatonic Scales. Finding their associated chords.

Applications: Music Theory, Harmony and Composition Analysis

[4] http://www.harmonicwheel.com/harmonic-wheel.php

Improchart

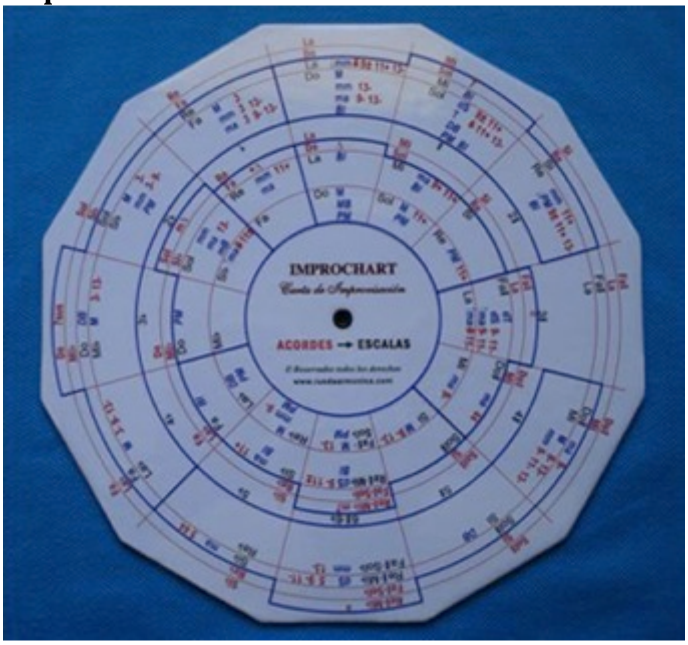


Illustration 16. Improchart by Luis Nuño

Summary of contents:

* Locator Scales: Scales available for improvising on each chord
* Types of scales considered: major, minor (natural, harmonic and melodic), Kids, Tone, Pentatonic, Blues and Bebop
* Tensions introduces each considered Chord Scale

Applications: Improvisation and Composition

3. Existing Systems and applications

3.1 Sequencer Software tools performing tonal MIDI transformations [5]

3.1.1 Ableton Live

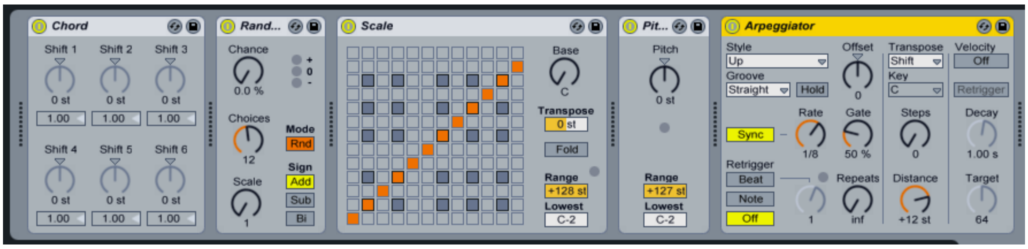


Illustration 17. Ableton's tools for performing tonal MIDI transformations

Chord
This effect assembles a chord, as the name implies, from each incoming note and up to six others of user defined pitch. The Shift 1-6 knobs allow selecting the pitch of the notes that contribute to the chord from a range of +/- 36 semitones relative to the original. Setting Shift 1 to +4 semitones and Shift 2 to +7 semitones, for example, yields a major chord in which the incoming note is the root.

Random
Random adds an element of the unknown to the otherwise commonplace pitch parameter. The Chance control determines the likelihood that an incoming note's pitch will be changed by a random value. You can think of it as being something like a dry/wet control for randomness.
The random value that determines the pitch change is created by two variables: The Choices control defines the number of different random notes possible, from a range of 1 to 24; the Scale control value is multiplied by the Choices control value, and the result dictates the pitches that random notes are allowed to have relative to that of the incoming note.

Scale
Scale alters incoming note pitch based on a scale mapping. Each incoming note is given an outgoing equivalent on the X-Y scale map of the effect: All incoming Cs, for example, might be converted to outgoing Ds.

Pitch
Performs a pitch shift as an offset to the incoming values and it can be defined in semitones or cents.

Arpeggiator
Is an arpeggio generator using different controllers such as direction: of movement, groove, pitch range, tonality, steps, etc.

---
[5] Ableton Live User Manual.

3.1.2 MAX For Live [36]

- **Max ANotePlayer** : a utility that functions as a keyboard
- **Max NoteScalar** : Some examples of different ways to fill a table object in order to scale incoming MIDI notes
- **Max PitchScalar** : The behavior of this device imitates the behavior of Live's Scale MIDI effect

3.1.3 Logic

The transformations offered in Logic are accessed through a dropdown menu and it is not very easy to modify the parameters of the transformation during performance.

Random Pitch: Sets a random pitch for note events.
Reverse Pitch: is a transformation that inverts the pitch of all note events.
Transpose: Transposes all note events by some “offset” set by the user as an amount of semitones to be added or subtracted to the original structure

3.1.4 Protools

Transpose: Only basic transpose as a fix offset for all music notes.

3.1.5 Cubase

The Logical Editor: The basic operation of the Logical Editor window is to specify the MIDI event that is going to be processed in what's known as the Filter Condition List (in the upper part of the window) that and then set an instructions in the Action List (in the lower part of the window) that determines the process or transformation applied to the event[6]. The logic editor Cubase offers many possibilities to perform midi transformations but not in real time.

3.2 Algorithmic Composers

Algorithmic composition is a process by which music is generated according to set of rules or algorithms. According to Lerhman [21] this programs are design so that a small action on the part of the user have a large effect on the output of the system. In general de idea would be to take advantage of the processing capabilities of the computer to make most of the decisions while the user determines the behavior of the system by modifying parameters.

[6] http://www.soundonsound.com/sos/may03/articles/cubasenotes0503.asp

Systems like Music Mouse (Laurie Spiegel), M (Dave Zicarellyi) and Band in a box (PG Music) are interesting implementations of these types of systems. Although they use musical knowledge in an interesting way, in my opinion, there is not a clear connection between the graphical interface and the knowledge used by the system. Musical knowledge could have a better graphical representation to provide the user a more logical interface to manipulate parameters in a semantic way.

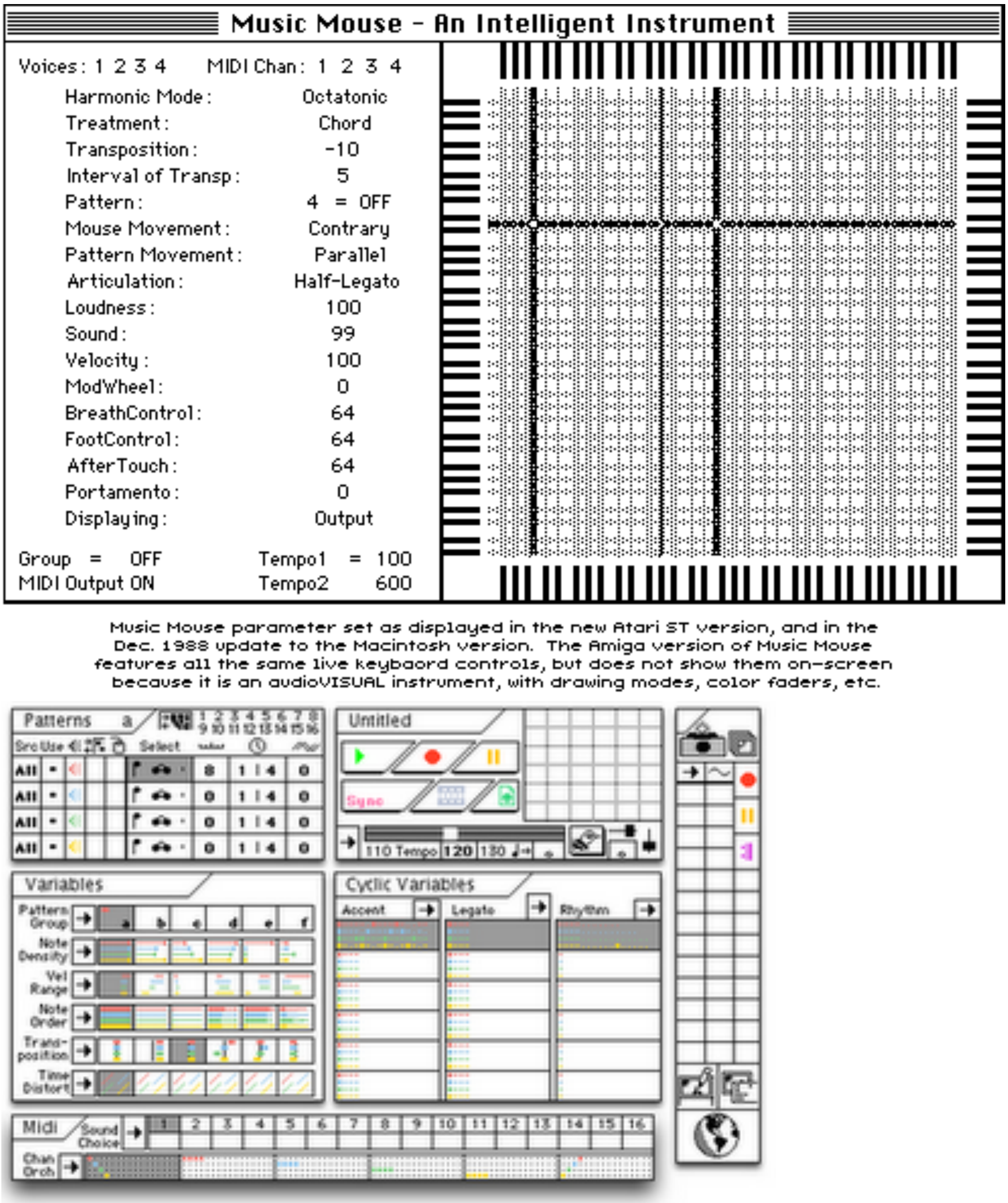


Illustration 18. Music Mouse graphical interface

In the case of band in a box, the user first configures de system and them let's it run, which is a form of asynchronous playing. In the case of our project we will be adopting a synchronous approach.

3.4 Harmony Improvisator (VST) [7]

Harmony improvisator it's one of the most similar applications to our project found actually in the market. We will first explain the general concept of this software and then discuss the main differences with our approach.

Characteristic stated by the authors of this software:

- *Perfect harmonic improvisation*
- *Composing with the rules of classical harmonic theory*
- *Complex cadences suitable for all styles of music*
- *Unique concept of harmonic pattern sequencing*
- *Automatic calculation of exciting harmonic suggestions*
- *Critical time advantage for creating harmonic frames of songs, soundtracks and arrangements.*
- *Rich database of contentful and complex chords - the systematic naming of which relates to their function in a musical context*
- *Improvisator automatically obeys voicing rules; it avoids 5th parallels, voice crossings etc.*
- *Improvisator provides clever harmonic suggestions for continuing a train of harmonic functions*
- *Creativity is stimulated by the opening up of unlimited space for harmonic experimentation*

Illustration 19. Harmony Improvisator

[7] http://www.synleor.com/improvisator.html

Discussion about Harmonic Improvisator:

This system is very relevant to our project since its final goal is to allow users to "navigate" concepts of tonal music. However the approach and strategies are very different to what we want to propose. From our viewpoint the main limitations of this system are:

- Graphical representation does not help the user understand the distributions of chords and their origin and tonal function.
- Music knowledge is based on Classical Music, which reduces the usability of the system to this genre.
- Notes played are determined by the system. The user has no control over the actual voicing's or rhythmic pattern in which they are being played.
- Tonality options are reduced to Major and Minor Natural

In the other hand there are many features that we find interesting such as: suggestions system, pattern sequencing, recently triggered chords, etc. This software has to be further analyzed to understand as for example voice leading, inversions, etc.

3.5 HyperScore

"Hyperscore is a graphical computer-assisted composition program intended to make composing music accessible to users without musical training as well as experienced musicians. The software maps complex musical concepts to intuitive visual representations. Color, shape, and texture are used to convey high-level musical features such as timbre, melodic contour, and harmonic tension."[8]

This project is very relevant to our design in the sense that it also uses higher level of abstraction for manipulating the features of tonality. It also separates the gesture (micro control, such as melodic contours) to the tonal possibilities (macro control, harmonic tension line). This project is mostly intended for scoring rather then live performances and it delegates many decisions about chord progressions to the computer.

[8] http://web.media.mit.edu/~mary/hyperscore.html

Illustration 20. Hyperscore

3.6 Installations

There are also some installations based on theories of tonal space and image recognition systems to generate sound according to the users movement and position.

"Wizard of Oz" whole-body exploration
(Holland, 2008)

Illustration 21. Installation of the wizard of Oz

3.7 Isomorphic keyboards[9]

Isomorphic keyboards use the same "shape" for any note sequence or combination. This idea is useful in our project because we are interested in generating similar outputs on gestures that have similar shape. In a normal keyboard the gesture used to perform a major scale in one tonality is different to the gesture required to produce the same scale in another tonality (due to the asymmetric shape of the piano). We are also interested in a graphical

[9] http://www.theshapeofmusic.com/

representation that is isomorphic to any similar chord progression, meaning same shape on the map, no matter which tonality we want to transpose it to. So from this system we will use the idea of similar shapes, producing similar chord progressions.

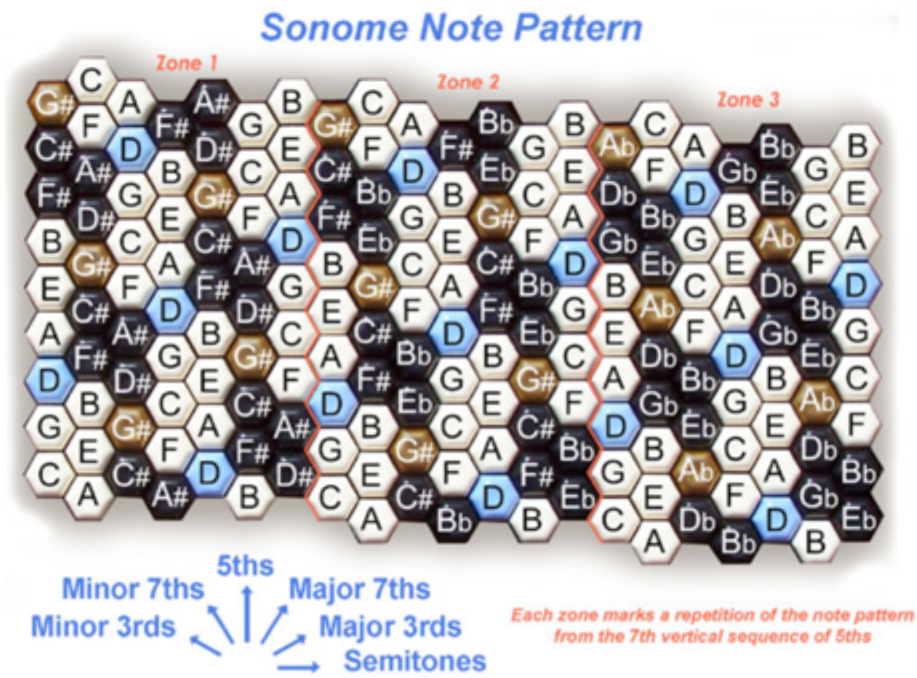


Illustration 22. Isomorphic keyboards, Sonome.

3.8 MIDI based applications in Music Education

In the chapter MIDI in Music Education [21] Lerhman explains the different uses of interactive systems for teaching. It divides his types of software in **theory software** ("Provides the user with a drill and practice environment for learning the basic elements of music theory and ear training"), **Performance and Practice software** ("Provides a performance environment such as a jazz ensemble, an orchestra rehearsal, or a piano lesson") and **Exploration software** ("Creates an environment unique to computers and MIDI by providing either a visual musical interface the user can manipulate or emulating procedural programming languages").

Because the system that will be design on this project is based on a graphical representation of knowledge related to tonal harmony, it could be possible to include features similar to this systems such as having an environment to configure the system, making it possible to adjust the difficulty level, giving additional information about the theory related to the system and having some sort of control and feedback of the performance.

From all these system, the most similar to our proposal is the Exploration Software because they allow, "navigating" concepts of music while performing (Music Mouse, Ovaltune, Max, etc.) [21]. We find of special interest the system called Harmony Grid, because it uses a graphical representation of some tonality concepts that the user can explore by moving the mouse. Even though this is not exactly the idea of our system, it uses an alternative graphical representation of pitch structure called "Harmonic grid". In this case the graphical representation is still a low level representation (each element represents a pitch) but in our case we are interested in representing higher levels of abstraction (Each element on the graphic might represent both a scale and a chord structure).

4. Conceptual framework in the design of interactive music systems

4.1 Creativity studies and musical interaction

It seems that there is a close relationship between states of flow and musical creativity. Csikszentmihalyi [19] proposes that the Flow is a situation that offers an optimal experience where there is an ideal balance between skill and challenge. In addition there are some other traits related with the state of flow:

- Focused attention
- Ease of concentration
- Clear cut feedback
- Control of the situation
- Intrinsic motivation
- Excitement
- Change in the perception of time and speed
- Clear goals

In the fallowing figure one can see how different emotional states are created by the relationship between challenge and skills [19]

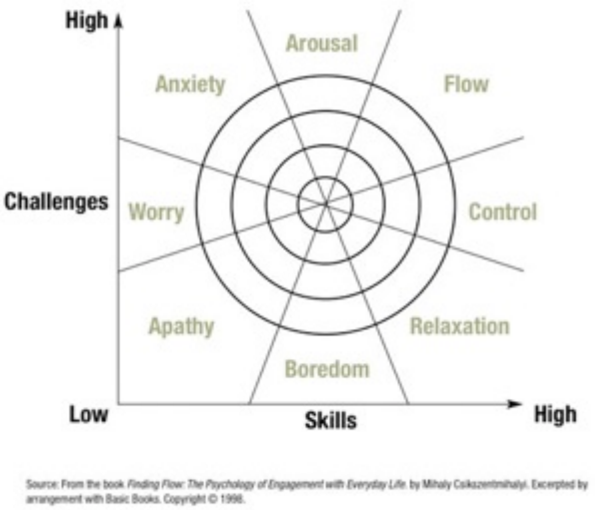


Illustration 23. Emotional States created by the relationship between challenges and skills

Pachet [20] proposes the question about if its possible to design interactive software that enhances creativity in music improvisation? The consequence of the studies of Pachet are the so called Interactive Reflexive Music Systems which attempt to induce states of flow by introducing a feedback loop in the music production process.

The concept of adaptability of the system to the level of skill and knowledge of the user will be used in our implementation (by selecting the amount of available choices). In order to interact with tonality concepts using traditional instruments, a high level of technical skills is required. For non-experienced musicians, reaching a state of flow while thinking at this low level of musical control (one to one) might be very difficult. Therefore the idea is that the system could assist the user by making some of the choices to overcome the lack of technical skills providing a way of exploring musical creativity from a tonality viewpoint.

4.2 Classifications and ideas of interactive systems

There is no standard classification of interactive music systems but several authors have used metaphors and taxonomies to describe the way interactive music systems work. It is interesting to have in mind the relationship between Flow and Creativity proposed by Pachet [19] while reflecting about these classifications and analogies.

Joel Chadabe [16] uses three metaphors to describe the types of interactions:

a) Sailing a boat on a windy day and through stormy seas; to represent that the performer is not fully in control of the output of the system because there are some stochastic processes happening.

b) The net complexity or the conversational model; It is very difficult for the performer to accurately predict the output of the system due to the complexity of the processes happening

c) The powerful gesture expander; extended or knowledge-based instruments that expand input control gestures for attaining complex musical outputs.

Other metaphors are proposed by Pressing [15] by making analogies with the traditional music making procedures: playing a musical instrument, conducting an orchestra, playing together (ensemble) with a machine and acting as a one-man band.

Laurie Spiegel [17] proposes the fallowing some concepts to evaluate or analyze interactive music systems:

1. Degree of human participation (completely passive listening versus total creative responsibility)
2. Amount of physical coordination, practice, and/or prior musical knowledge required for human interaction.
3. Number of manipulable variables in real time
4. Number of manipulable variables by the user (not the coder) prior to real-time output ("configurability").
5. Amount of time typically needed to learn to use a system.

6. Balance of task allocation (human versus computer) in decision-making in the compositional realms of pitch, timbre, articulation, macrostructure, etcetera, and/or in labor-intensive tasks such as notation or transcription
7. Extensiveness of software-encoded representation of musical knowledge (materials, structures, procedures)
8. Predictability and repeatability (versus randomness from the user's viewpoint) of musical result from a specific repeatable human interaction.
9. Inherent potential for variety (output as variations of a recognizable piece or style, versus source not being recognizable by listeners)
10. Ratio of user's non-realtime preparation time to real-time musical output.
11. Degree of parallelization of human participation
12. Degree of parallelization of automated processing
13. Number of discrete non-intercommunicative stages of sequential processing (e.g. composer-performer-listener or coder-user-listener versus integrated development and use by single person or small community)
14. Degree of multi-directionality of information flow
15. Degree of parallelization of information flow
16. Openness versus finiteness of form, duration and logic system

Even though very extensive, this list helps to reflect about the concept design of the music system to be implemented in this project.

Another interesting classification of Interactive systems us proposed by Rowe [18].

- **Score driven vs. performance driven.** Score driven programs compare the input of the system with some predetermined event collections or music fragments while performance driven don't expect an input with traditional descriptors used in written music.
- **Transformative, Generative or Sequenced.** Transformative methods take some existing material and transform it to produce variants. Generative methods use sets of rules to produce complete musical output based on the stored knowledge of the system (Durations, pitches, ranges, etc.). Sequenced use prerecorded music fragments and respond to some real-time input that introduces subtle variations.
- **Instrument and player paradigm.** In the case if the Instrument paradigm the idea is to maximize the bandwidth between the musician and the output by creating an instrument that takes as much information from the player as possible. In the case of the player Paradigm the idea is that the system has its own personality thus resulting in a "duet" performance type.

4.3 Intelligent instruments and interactive composing

The intervention of computer's in music performance and composition can have many different variants. The ability of computers to make many decisions per second to assist the performer was defined by Laurie Spiegel and Max Matthews as "Instrument Intelligence". The added intelligence suggests a continuum that may range from absolutely passive conventional instruments, to fully autonomous (human independent) machines [1]. Between this two extremes are the systems where the user shares control of the musical output with the instruments "Intelligence".

In the case of our project, the idea is to include musical knowledge regarding the way tonal harmony works in popular and modern music (presented in a graphical way) to allow the user to perform at a higher level of abstraction. As Jorda [1] proposes "Instead of using predetermined pitch sequences, each note to be played could, for intance, result from a combined decision made by both the player and the instrument". Laurie Spiegel said in 1993 in an interview with Gagne " Intelligent instruments let people play the music in a compositional level".

Even though it is not in the scope of this project to develop a philosophical discussion about the implications and accuracy of the terms "Intelligent instruments and interactive composition" the idea of a system with knowledge that shares responsibility with the user over the musical output matches the general concept of design of the system being developed in this project.

4.4 Efficiency

One clear advantage of digital instruments is that of their efficiency. Delegating some of the tasks to the "intelligence" of the instruments allows users to work in a different way than the one commonly used in the context of traditional instruments (one to one control over pitch, timber and dynamics). Jorda [1] proposes the fallowing equation for defining Musical Efficiency

$$MusicInstrumentEfficiency_{Corrected} = \frac{MusicalOutputComplexity \times DiversityControl}{ControlInputComplexity}$$

This term was used to describe the learning curve of an instrument as the relationship between efficiency against time spent learning. In addition to this, as the learning curve is a gradual process, some musical tasks are only accessible after some part of the learning curve has being reached. For example to experiment in a piano with concepts such as modulations and complex chord progressions, lots of technical skills and music knowledge is required. So from my viewpoint, some digital instruments not only might have a steeper curve but also might start in a point different from zero, due to the knowledge that is added by the instrument.

4.5 Pitch Transformations

There are many ways to modify pitch in digital instruments. In this case we are interested in pitch transformations that modify the control signal that trigger sound rather then some process over the actual audio signal. Since MIDI is a standard in most commercial products, we are interested in how we can modify MIDI notes to control the resulting pitches.

The most basic pitch transformation is transposition by which the MIDI notes of a sequence are shifted by adding, positive or negative, amounts of semitones. There are also some pitch correction processes that music knowledge about scales and modes to "correct" the pitches by quantizing them to the closest value that the scale "allows".

Software like MAX, Pure data and Reaktor allow almost endless possibilities to modify control data, but most of the actual implementations of pitch transformation use low level knowledge (such as scales) and to my knowledge there are no system to perform pitch quantization's that take into account how this different scales are related. In my opinion, knowledge of tonal harmony can be used to organize these transformations according to hierarchies and tendencies making it more easy and intuitive to make modifications in real-time.

In the section 3.1 "Sequencer Software tools performing midi transformations" there is a short description of the MIDI processes available in commercial sequencer software that relate to our project.

4.6 Digital Lutherie Decalogue: Twenty Five Steps Towards the Future

Due to the amount of possible choices in making a digital instrument, it is necessary to set the basic principles that could guide the design process. Jorda [1] proposes in his Digital Lutherie Decalogue a very complete set of ideas that serve as a conceptual framework for the design process.

1. New *music* tends to be the result of new techniques, which can be both compositional and/or *instrumental.*
2. New instruments will be able to survive and succeed in the measure they are truly *innovative*; i.e. they have something new to bring to music, and not merely because they are based on novel, previously unavailable technologies.
3. It is therefore crucial to identify the quintessence of new digital instruments; what they can bring that is essentially original to the act of music performance; how can they redefine it.
4. Moreover, new instruments will manage to be better if luthiers do not over look the history of traditional instruments.
5. Learning from the past does not merely mean emulating it. It also means to try avoiding or improving upon passed errors and limitations (the past was not perfect).
6. One of the aspects that should be clearly improved is that of *efficiency*. Traditional instruments take years to master, whereas, given the speed at which technology and fashion shift in our current 21st century, new instruments have to hook from the first minute. We cannot rely anymore on persistent parents that insist on bringing their children to the conservatory, or on patient students to whom we promise the light after ten years of sacrifice.
7. New instruments whose output is based on traditional paradigms, such as one-to-one control of pitch+timbre+amplitude, have a hard time competing with existing traditional instruments. They probably can only contend on the grounds of efficiency (providing comparable results with less knowledge or effort).
8. These new 'traditionally-modeled' instruments with increased efficiency may appeal to non-musicians and to dilettante, which is good. However, it will be much harder for

them to appeal to advanced musicians as well. Advanced musicians will preferably look for new-fangled possibilities.

9. New instruments have to profit from computers' intelligence, with their ability to remember, to make decisions on the fly, to run multiple, concurrent processes in parallel.
10. In such cases, the performer will need to share and delegate part of the control of the music being created to the instrument; such as the traditional composer delegates on the performers.
11. By running processes at different temporal and formal scales and different levels of complexity, new instruments naturally surpass the one-action to one-event model inescapable in all traditional instruments. New instruments are not only sound producers but also become music producers.
12. Performing with such powerful instruments should not mean leaving all the musical decisions to the instrument, though. Just like the traditional composer is responsible for the music played by the performers, so should the new performer be responsible of the music performed *together with* the instrument. Playing music is a 'serious' activity, different from 'playing with music' (also very important but not studied here).
13. An instrument of these characteristics will probably involve many internal dimensions or control parameters. Otherwise it will always seem to play 'the same composition'.
14. The feeling of power and macro-control these instruments can bring to their performers, should not let us forget about the expressive nuances and the time precision mechanisms, which traditional instruments have always incorporated.
15. The performer must thus be able to affect all these dimensions: both the metacontrol of ongoing processes and the microcontrol of final parameters should be permitted. All of them with the maximum simplicity, flexibility and speed.
16. That means that the many internal dimensions of the instrument, should not be controlled by four or five input dimensions, leaving all the dirty work to some clever mappings.
17. To allow this type of control, new instruments have to be 'wider' rather than 'deeper'. 'Wide' instruments permit a better direct access to all of their complexity.
18. Since not all the parameters can be controlled simultaneously, these instruments need to integrate intuitive and efficient multiple sample/hold/return/bypass options.
19. These mechanisms favor a type of selective or asynchronous playing (not all the parameters are permanently modified; not all the processes are equally active).
20. In a 'wide and concurrent instrument', multi-user possibilities, though not a must, can represent an appealing added value. A multi-user approach can enrich the instrument's bandwidth without provoking a single-user overload.
21. Wide instruments demand wide controllers or interfaces.
22. Moreover, sophisticated and complex concurrent instruments will benefit from interfaces that reflect and help to understand the instrument's ongoing internal mechanisms.
23. The potential of computer graphics for representing and monitoring complex processes, is not easily surmounted. This is probably the reason why many of the more interesting recent instruments, are screen based. While, the mouse is a very limited controller that we should definitely try to avoid.
24. Screen based visual feedback can still be used in combination with physical controllers, but in these cases an undesirable indirection component is added (the performer does not play IN the screen).
25. For including real-time interactive visualizations and, at the same time, overcoming mouse limitations without adding indirections, interfaces should be able to reflect their own states and behaviors. They should integrate, like the abacus, both representation and control.

4.7 Mapping

Mapping is a crucial stage of the digital music instrument design process. For the scope of this project, the actual mapping of gesture input will not be the main focus but some general strategies will be mentioned. Some of these concepts have being though mainly to map gesture to synthesis but they can still be applied to control data.

The main strategies for mapping are:

- One to one: One parameter of control is driven by one gesture
- One to many: One gestural parameter can influence more then one "Synthesis" or control parameter.
- Many to one: One parameter of "Synthesis" is driven by two or more gestural parameters.

4.8 Gesture and Inputs for control.

Even though the aim of the project is at designing a system to transform control Data and not the generation of itself, its important to know which types of inputs could be used in order to design a system capable of adapting to different input formats.

Instrument-like

Corresponds to reproductions of traditional instruments that send MIDI or control data instead of producing sound. This category includes MIDI instruments in the form of: drum sets, keyboards, flutes, saxos, violins, guitars, etc. They use the MIDI protocol to send note events and other control change messages determined by the MIDI protocol.

Extended controllers and Hyper instruments

Consist in the use of additional sensors to expand the dimensions of the instrument. As an example of this we could have for example a guitar with accelerometers on it to transform sound according to the movement of the instrument.

Alternative Controllers

A large set of additional inputs [1] can be used. Jus to mention some of them we have: batons, bodysuits and exoskeletons, bio signals, playing with space, joysticks and gamepads, 3D positioning and home-market gloves, graphic tablets, MIDI boxes, graphical interfaces, microphones, tangible interfaces, image recognition systems.

5.Music Knowledge used in the system

After discussing the interaction and music perception concepts of the system we move know to the music theory section of the project. Here we will mention the most common features explained in jazz harmony books [27][29][30]. As it was mention in section 2.2, Jazz harmony has its origin in traditional music from Europe but has being largely influenced by other genres, initially by African traditional music and afterword by many other genres, producing a very wide spectrum of possibilities in the use of chords and scales.

5.1 Diatonic Harmony

The diatonic harmony consists on the construction of the chord of each degree, based on the structure of the major scale. Some characteristics of this type of harmony are:

- The characteristic tone is the 4^{th} degree due to its instability.
- Tonic Chords: Are the ones that don't contain the 4^{th} degree.
- Subdominant Chords: are the ones that contain the 4^{th} degree but not the diatonic tritone (without the 7^{th} degree)
- Dominant Chords: The chords that contain the diatonic degree (4^{th} and 7^{th})
- VII-7(b5): its not considered a dominant chord even though it contains the diatonic tritone.

If we use the diatonic degrees for the construction of the chord and scales of each degree we obtain the fallowing:

- 1^{st} degree…………….Ionian mode………Imaj7………..Tonic
- 2^{nd} degree…………...Dorian mode……...II-7……………Subdominant
- 3^{rd} degree……………Phrygian……………III-7…………..Tonic
- 4^{th} degree……………Lydian………………..IVmaj7………Subdominant
- 5^{th} degree……………Mixolydian…………V7……………..Dominant
- 6^{th} degree……………Aeolian………………VI-7…………..Tonic
- 7^{th} degree……………Locrian……………...VII-7(b5)

5.2 Modal interchange

Modal interchange occurs when natural minor chords are used during major key progressions (sometimes called borrowed chords). The characteristic note of natural minor is scale degree b6. The chords in this mode can be categorized as Minor tonic (Chords that don't contain the b6 degree) and Non Tonic Chords (Chords containing the b6 degree). The non-tonic minor chords can be heard as functionally sounding like minor subdominant chords in the primary major key.

The remaining three chords are functionally tonic minor sounds in the major key. *"The tonic minor chords scales usually contain the natural 6 scale degree since b6 represents the functional sound of the subdominant minor chords"* [27].

The idea of modal interchange is to perceive movement in the tonality while keeping some sort of reference on a primary major scale. Therefore in the tonic minor chords the natural 6 is used instead of the b6.

I-7: Uses the Dorian scale

II-7(b5):

"The scale usually used for this chord is the Locrian - Mixolydian (b9,b13)".

bIIImaj7: Uses the Lydian scale (The #11 represents the natural 6 degree of the I scale)

V-7: In normal circumstances the V-7 chord would be analyzed as the related II-7 of V7/IV, not as a V-7, and therefore using a Dorian Scale (avoid 13). Also it is possible to cadence to a tonic minor or major but in any case it will use the Dorian Scale.

The origin of bVIImaj7 and V-7 can also be the modal interchange from Mixolydian.

The scale used for IV-7 would be Dorian and for the IV-(Maj7) the Melodic Minor.

bVImaj7: The chord scale for bVImaj7 is Lydian reflecting its nontonic function.

bVII7: Uses a Lydian b7 most of the time, reflecting the implication of minor but its use in major, and its expected root motion to tonic that Is not down a perfect fifth. (Both bVI7 and bVII 7 are typical examples of dominant chords without dominant function)

"SUMMARY OF SUBDOMINANT MINOR CHORDS" [27]

IV-7, IV-(maj7), IV-6

II-7(b5)

bVII7

bVImaj7, bVI6, bVI7, bIIMaj7

The previous definition of modal interchange is based on the theory explained in the Jazz harmony Book by Nettles but other jazz methods don't restrain the chord and scale selection to this options but instead generate each degree from the different modes (minor natural, harmonic, melodic and Dorian, mixolydian, Phrygian etc.).

After reading several methods for Jazz Harmony, the conclusion was that many of this “barrowed chords” provide variety of color so they should be included in the representation. The fallowing table shows a summary of the chords obtained from the parallel modes (Same tonic but different alterations)

Table 1. Chord species produced by the different modes

					Common	Modal	Interchange	Chords
	Natural	**Harmonic**	**Melodic**	**Dorian**	**Lydian**	**Mixolidian**	**Phrygian**	**Locrian**
I	I-7	I-maj7	I-6 (I-maj7)	I-7	Imaj7 (Lydian)	I7	I-7	I-7(b5)
bII							bIIMaj7	bIImaj7
II	II-7(b5)	II-7(b5)	II-7	II-7	II7 (rare)	II-7 (aeolian)		
bIII	bIIImaj7, bIII6	bIII+maj7	bIII+maj7	bIIImaj7, bIII6			bIII7	bIII-7
III					III-7 (Aeolian)	III-7(b5)		
IV	IV-7, IV-6	IV-7, IV-6	IV7, IV6	IV7, IV6		IVmaj7(Ionian)	IV-7	IV-7
#IV					#IV-7(b5)			bVmaj7
V	V-7	V7, V7(b9)	V7, V7(9)	V-7	Vmaj7 (rare)	V-7	V-7(b5) (rare)	
bVI	bVImaj7	bVImaj7						
VI			VI-7(b5)	VI-7(b5)		VI-7 (Phrygian)	bVImaj7	bVI7
bVII	bVII7			bVII maj7		bVIImaj7	bVII-7	bVII-7
VII		VII°7	VII-7(b5)		VII-7			

Each mode has its one personality, and even though the feeling produced by music depends on many factors, the historical inheritance has determined a certain way in which people tend to tag these modes. From the book Music Composition For Dummies[10]

> ***Dorian***
> *The Dorian mode is most commonly heard in Celtic music and early American folk songs derived from Irish melodies. Songs written in Dorian mode sound melancholy and soulful because the final note of the scale doesn’t quite resolve itself, so it feels almost like a question left unanswered. The Dorian mode sounds melancholy and full of bittersweet longing.*
> ***Phrygian***
> *The Phrygian mode can give your music a bit of exotic spice. Most flamenco music is written in the Phrygian mode, which has a bright, Middle-Eastern sound to it that works well with folk and traditional dance music. Many modern composers*

[10] Music Composition For Dummies by Scott Jarret and Holly Day. Even though we don’t take this as a very serious reference book, some of the concepts here reflect they way masses tend to understand music, a sort of “collective understanding”.

and guitarists commonly use Phrygian modes with major scales (instead of minor scales) because it sounds brighter and less melancholic than the minor scale.
Lydian
The Lydian mode has something of a surprising, jazzy feel to it.
The Lydian mode is the complete opposite of the Ionian mode/major scale, so it feels as solid and bright as a major scale but the intervals are surprising and unexpected. This is a popular mode among jazz musicians who enjoy using a mixture of major and minor chord progression in inventive ways.
Mixolydian
The Mixolydian mode is often used for blues and bluesy rock music.
Mixolydian is similar to Lydian in the sense of having a major-scale feel with minor intervals, and it's a great mode to work within to give a bluesy feel to your compositions. Mixolydian mode is another popular scale for solo musicians looking for a counterpoint to the Ionian key of the song.
Aeolian (natural minor)
The Aeolian mode can convey great sorrow, regret, and despair.
The intervals of Aeolian mode create the same feel as many modern blues songs. Songs composed in Aeolian mode have a strong sense of sadness. The final note of an Aeolian scale feels resolved in a completely different sense than the final note of the Ionian. If the Dorian mode reflects melancholy, the Aeolian reflects despair.
Locrian
Locrian mode is considered to be so unstable that most composers consider it unworkable. There are few songs written in the Locrian mode, which has led some music theorists to label it a "theoretical" mode. You find it occasionally used in heavy metal. This mode exists because all seven notes of the Ionian scale could form it in a mathematical sense, but the relationship between intervals in the Locrian mode is difficult for many composers to work with. Music that is composed within this mode sounds unsettling, disturbing, and just a little bit off.
The Locrian mode sounds a bit twisted and wrong.

5.3 Secondary Dominants V7/X

Secondary dominants are used very often in classical, jazz and popular music. They constitute the V7 degree relative to any other degree of the tonality[11] (Diatonic and non diatonic). The nomenclature used to define these chords is V7/X where X is the reference degree. For example the dominant of the ii degree would be written as V7/ii.

The chord scale used for secondary dominants is usually the same notes as the target chord X, but using the major 3rd and minor 7th of the V7 chord. The major 3rd and minor 7th give the dominant character, and the tendency to move to the target chord is suggested by selecting the rest of the notes from the target X chord scale.

5.4 Substitute Dominants (tritonic substitution) SubV7/X

[11] In some methods they consider secondary dominants only the V7 of the diatonic degrees but because the use of dominant chords over non-diatonic degrees is very common we will use this definition.

Substitute dominants are originated from the tritonic substitution. The characteristic notes of dominant chords are the ones contained in the diatonic tritone formed between the 4th and 7th degree of the scale (3rd and 7th of the dominant chord). If the root of this chord is shifted by a tritone (6 semitones) one can obtain the tritonic substitution. This is explained better through an example.

Tonality: C major
V7 chord: G7
Characteristic notes: B (3rd) and F (7th)
Root note → shifted by a tritone: G → Db
Tritonic substitution: Db7
Characteristic notes: F (3rd) and B (7th)

The nomenclature to refer to these chords is SubV7/X where X is the target chord. For example in the case of C major tonality the SubV7/I would be Db7. Substitute dominants can be used over any other chord used in the tonality.

According to the book "The chord Scale Theory and Jazz Harmony" [27] any chord using the **mixolydian** scale has the tendency to resolve by a root motion of a descending fifth. Because in the case of Substitute dominants the intention is to resolve down a semitone, the **Lydian b7** is more commonly used.

5.5 Relative II

Because root motion by 5th is very strong, it is very common to precede the dominant chords by their relatives II's. This is the base of very common patterns in jazz and popular music called II V I. The term relative refers to the fact that the I degree could be any chord that we are using within the tonality. For example if we are in C major and we want to reach the V degree (G7) we could construct a II V I relative to G7 which would be A-7 (rel II-), D7 (V7/V), G7. We could use the same principle with the substitute dominant resulting in A-7 (rel II-), Ab7 (subV7/V), and G7.

In case the ending chord of the II V I progression is minor; usually the II chord used is a half diminished seventh chord (intervals 1,b3, b5, b7). This chord comes from the natural minor scale.

5.6 Diminish Chords L°7

Diminished chords can be originated as the 7th degree of the harmonic minor mode. Since it contains 2 tritone intervals (from root to minor fifth and from minor third to diminished seventh) it is very unstable. Some of the most common uses of this chord are:

- Passing chord: working as a link between 2 chords separated by a tone

- “Bordadura”: A diminished chord that resolves on the same chord that preceded it.
- Not prepared: The root motion takes a “jump”.
- Chromatic: diminished chords use for voice conduction (e.g. C6, C°7, C6).
- Dominant: They can work as secondary dominant when they resolve with a root motion of an ascending semitone.
- Delayed resolution: When taking the stronger part of the harmonic rhythm. For example F°7 F6.

There are many scales used for this chord but the most used on is the symmetric diminished = TST S TST = 1,2, -3rd, 11,o5th, b13, maj7.

5.7 Non-diatonic chords of common use

+7 and 7(b5)

This is a non-diatonic chord that only exists in the bIII of the harmonic and melodic minor mode. However it is usually used as an alternative to the V7 chord (the augmented 5th of the V+7 chord is half step from the 3rd of the I chord)

The scale usually used for this chord is the whole Tone Scale consisting of the scale degrees: 1,9,3, #11, #5 or b13, -7.

Another alternative for the V7 degree is the 7th(sus4) using in this case the Mixolydian scale with avoid note =3.

#IV -7(b5)

This chord comes from a Lydian modal interchange. Note that this chord has the same notes as the Vmaj7 chord with except for the root that has being raised a semitone.

This chord is commonly used in the fallowing ways:

- II-7 relative to V7/III having a function of subdominant minor referred to the III degree.
- Delayed entrance for the IV degree: When the #IV-7(b5) precedes the IV. It is considered as an altered subdominant.
- “Sensible de dominante”[12]: When it is used as a passing chord to the V7. For example: IVmaj7, #IV-7(b5), V7.
- Substitute in a “cadencia rota”[10]: The V7 can resolve to the #IV-7 instead of to the Imaj7.

[12] Need to look for the corresponding English terminology.

5.8 Chord Scale Theory

The chord scale theory is the study of the scales to be used with each chord. The same chord can use different scales depending on its tonal function. Chord species (chord types) determine some components of the chord scale but the rest of the notes are determined by the relationship of the function of the chord and the tonal center [27].

Chord scales have the fallowing components (scale qualities):

1) Chord tones: the notes that belong to the seventh chords structure.
2) Tensions: Additional tones which create special sound colors and tensions.
3) Avoid notes: tones of a chord scale, which sound very dissonant and therefore are avoided harmonically. They are non-chord tones that are half step away above a chord tone

Although avoid notes do not occur harmonically, their inclusion melodically is what defines a specific chord function for a chord. Avoid notes are the pitches from which each chord derives its characteristic sound.

There are many possible choices and this subject has to be study in more depth. As a starting point we will mention the chord scales usually used for the diatonic degrees:

maj7

A maj7 chord occurs in the I and IV degrees of the major scale. When the chord functions as the I degree, the scale that is used is the Ionian. When it corresponds to the IV it uses the Lydian (#4). In the case of modal interchange: bIIImaj7 and bVIMaj7 use the Lydian mode.

Imaj7 = Ionian…………………………………………………..Avoid note = 4
IVmaj7 = Lydian

-7th

II-7th= Dorian Scale (b3,b7)……………………………….Avoid note = 6
III-7th= Phrygian (b2,b3,b6,b7)…………………………Avoid note = b2,b6
VI-7th= Aeolian (natural minor = b3,b6,b7)…………Avoid note = b6

In the Dorian scale the 6 is an avoid note because it creates a tritone with the minor third. The tritone is the key ingredient of a dominant function chord and that's why it's avoided.

-7(b5)

VII-7(b5) = Locryan Scale (b2,b3,b5,b6, b7)…………Avoid note = b2

7th

There are many scales for this chords but the most used ones are.

V7 = Mixolydian (b7)……………………..…………………..Avoid note = 4
?7 = Lydian b7 (#4,b7)
SubV7/X = Lydian b7

Finding the appropriate chord scale depends not only in the species of the chord, but also in the previous chord, target chord and harmonic function. Even though there are some guidelines to choose a scale that functions well, this is a subjective process and therefore there are discrepancies between authors. As an attempt to organize and choose the different scales that could be used in our prototype the fallowing table has being constructed.

Table 2. Chord scales and their relationship to the chord's function

Chord Species	Degree	Mode	Function	Scale name	Scale degree	Avoid Note	Tensions
Lmaj7,Lmaj6	I,IV	Major	Diatonic	Ionian	1,2,3,4,5,6,7	11=4	9,13
Lmaj7,Lmaj6	bIII,bVI	Minor Aeolian	Intermodulation	Ionian	1,2,3,4,5,6,7	11=4	9,13
Lmaj7,Lmaj7	bVI	Minor Harmonic	Intermodulation	Ionian	1,2,3,4,5,6,7	11=4	9,13
L-7	II	Major	Diatonic	Dorian	1,2,-3,4,5,6,-7	6=13	
L-7	III	Major	Diatonic	Phrygian	1,b2,-3,4,5,b6,-7	b2, b6	
L-7	VI	Major	Diatonic	Aeolian/natural	1,2,-3,4,5,b6,-7	b6	
L-7	I	Minor Aeolian	Intermodulation	Aeolian/natural	1,2,-3,4,5,b6,-7	b6	
L-7	IV	Minor Aeolian	Intermodulation	Dorian	1,2,-3,4,5,6,-7	6=13	
L-7	V	Minor Aeolian	Intermodulation	Phrygian	1,b2,-3,4,5,b6,-7	b2, b6	
L-7	II	Minor Melodic	Intermodulation	? Ethis or Dorian?	1,b2,-3,4,5,6,-7		
L-7(b 5)	VII	Major	Diatonic	Locrian	1,b2,-3,4,b5,b6,-7	b2	
L-7(b 5)	II	Minor Aeolian	Intermodulation	Locrian	1,b2,-3,4,b5,b6,-7	b2	
L-7(b 5)	II	Minor Harmonic	Intermodulation	?????	1,b2,-3,4,b5,6,-7	b2	
L-7(b 5)	VI	Minor Melodic	Intermodulation	Locrian	1,b2,-3,4,b5,b6,-7	b2	
L7	V	Major	Diatonic	Mixolidian	1,2,3,4,5,6,-7	11=4	
L7	bVII	Minor Aeolian	Intermodulation	Mixolidian	1,2,3,4,5,6,-7	11=4	
L7	V	Minor Harmonic	Intermodulation	????	1,b2,3,4,5,b6,-7	b2, 11=4	
L7	IV	Minor Melodic	Intermodulation	Lydian b7	1,2,3,#11,5,6,-7		
L+7			Non diatonic	Whole tone	1,2,3,#11,b6,b7		
L7(b5)			Non Diatonic	Whole tone	1,2,3,#11,b6,b7		
$L^{0}7$			NonDiat /passing	Symetric Diminished	1,2,-3,11,b5,b6,bb7,7		
$L^{0}7$	VII	Minor Harmonic	NonDiat /passing	Symetric Diminished			
L7	V7/II	Major???	Sec dominant II	Mixolidian b13	1,2,3,4,5,b13,-7	11=4	9, b13
L7	V7/III	Major???	Sec dominant III	Mixolidia b9,#9,b13	1,b9,#9,3,4,5,b13,-7	11=4	b9,b13
L7	V7/IV	Major???	Sec dominant IV	Mixolidian	1,2,3,4,5,6,-7	11=4	9,13
L7	V7/V	Major???	Sec dominant V	Mixolidian	1,2,3,4,5,6,-7	11=4	9,13
L7	V7/VI	Major???	Sec dominant VI	Mixolidian b9,#9,b13	1,b9,#9,3,4,5,b13,-7	11=4	b9,b13
L7			All Sec Domin	Altered	1,b9#9,3,b5,b13,-7	No	
L7			All Sec Domin	Whole tone	1,2,3,#11,b6,b7		
L7	bII	Major	Substitute Dom	Lydian b7	1,2,3,#11,5,6,-7		
L7	subV7/X		Sub Dom if any d	Lydian b7	1,2,3,#11,5,6,-7		

5.9 Harmonic Movements

There are many possibilities regarding harmonic movement but to organize and understand these concepts we will mention the patterns more commonly used as a guideline for the design of the graphical representation (easy chord progressions should have easy access in the representation).

The main harmonic movements within diatonic chords are shown in the fallowing graph:

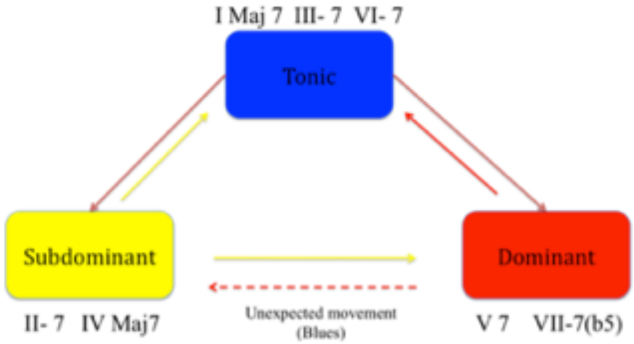


Illustration 24. Tendency for harmonic movements between tonic, subdominant and dominant chords

The reason for this tendency is the associated "stability" condition of each of these functions

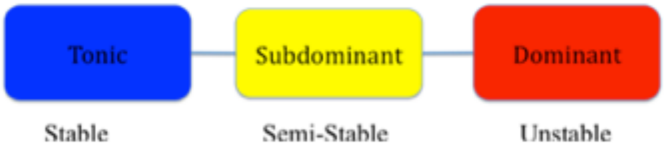


Illustration 25 Stability of Tonic, Subdominant and dominant chords

Root Motion

Some authors classify the strength of harmonic motions according to the intervals produced between the roots of the chords [30].

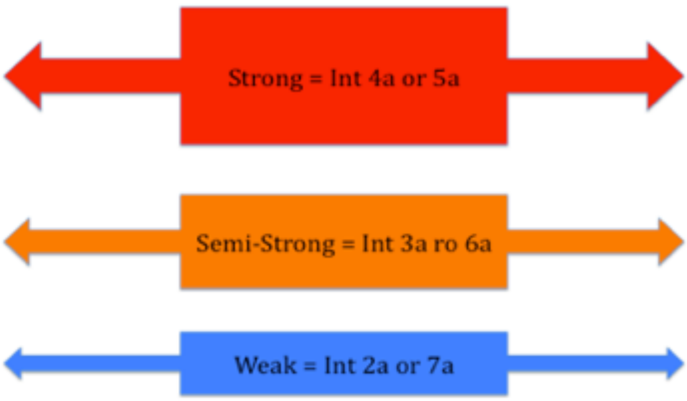


Illustration 26. Strength of root motion

Cadences

Cadences are sequences of chords that lead to a "resting" chord.

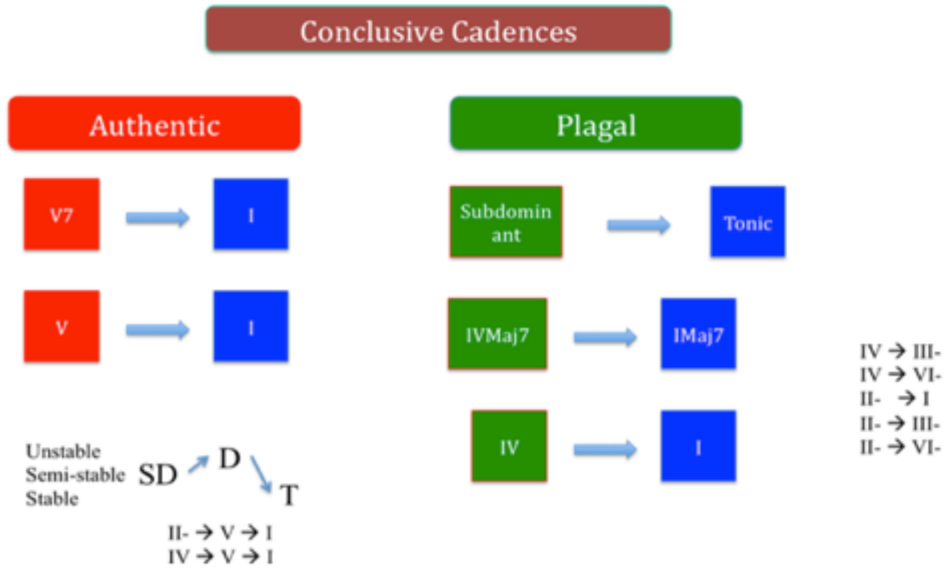


Illustration 27. Conclusive Cadences

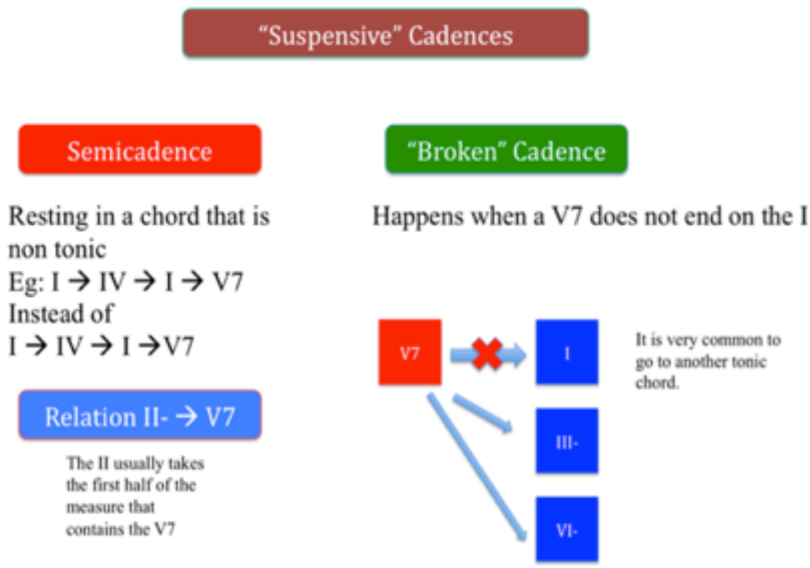


Illustration 28. Suspensive Cadences

Sequential Dominants

D7 → G7(#9) → C7 → F7(#9) → BbMaj7

The root motion is down a perfect fifth (Strong root motion).

Interpolated Sequential Dominants:

Tonality: Bb

Bmaj7 → G7 → Db7 → C7 → Gb7 → F7 → Cb7 → Bmaj7

Sequential Dominants
Interpolated Sequential Substitute Dominant

This movement is quite common during the turnaround, prior to the repeating of a phrase.

Sequential Substitute dominants

Sequence of substitute dominants normally ending on a diatonic degree

Tonality: Bb

D7 → Db7 → C7 → Cb7 → BbMaj7
III7 → Sew Subs Dom. → Seq. Subs Dom. → SubV/I → Imaj7

Turnarounds

A very common chord sequence used in jazz is called turnaround. The basic structure is:

Imaj7	VI-7	II-7	V7	Imaj7

Many variations of this structure can be made replacing chords with others of the same harmonic function or using tritonic substitutions, substitute dominants and secondary dominants. Some examples of this are:

III-7	VI-7	II-7	V7	Imaj7
III-7	VI7	II-7	V7	Imaj7
III-7	VI7	II7	V7	Imaj7
III-7	VI7	II-7	IIb7	Imaj7
III-7	VI7	bVI7	IIb7	Imaj7
III-7	IIIb7	bVI7	IIb7	Imaj7
VIIb7	IIIb7	bVI7	IIb7	Imaj7
VIIb7	VI7	bVI7	V7	Imaj7

5.10 Modulations

Modulation consists on changing from one tonal region to another. The main techniques used for modulating are described bellow.[13]

Direct modulation

Direct modulation is the most abrupt type of modulation because there is no preparation for the change and it is used to create surprise in the listener.

Common chord modulation

Common chord modulation is based on the use of chords that are common to both tonalities (pivot chords). This is only possible between tonalities that differ in less then or exactly 2 alterations (less than two steps in the circle of fifths). This concept is not included in the actual graphical representation and might be interesting for future work.

Secondary chord modulation

Secondary chord modulation happens when the chord is diatonic to one of the tonalities and related to the other one. For example the secondary dominant of the VI degree in Eb (VI=C, V7/VI=G7) could be use to modulate to C.

Relative chord modulation

Relative chord modulation is based on the use of chord that are relative to both tonalities but non diatonic to any of them.

[13] This terminology has been translated from Herrera [30]. It is necessary to find the proper translation.

6. Prototype development

The fallowing section explains the design process of the prototype. The initial graphical representation used was based on the tonal and region space of Lerdahl. Even though this approach had strong bases from music perception studies, the resulting graphic interface was not very compact, therefore not practical. This model will be explained very briefly in the fallowing section but a more in depth description can be found in the appendix section “Another graphical representation for tonality”. The second representation is used for the development of the software prototype that was programmed using Max for Live as a MIDI effect.

6.1 Proposed Graphical Representation 1

The first approach was to start from the chordal and regional spaces of Lerdahl and afterwards add the main concepts used in popular and jazz music. The new additions were:

1. Map based on tetrads instead of triads.
2. Addition of minor modes on the map (melodic, harmonic and natural)
3. Inclusion of non diatonic chords that are of common use (Variations of the V degree)
4. Combination of different modes in each chordal region (instead of having separate model)
5. Templates to show chord progression tendencies.
6. Color code for finding common root chords.

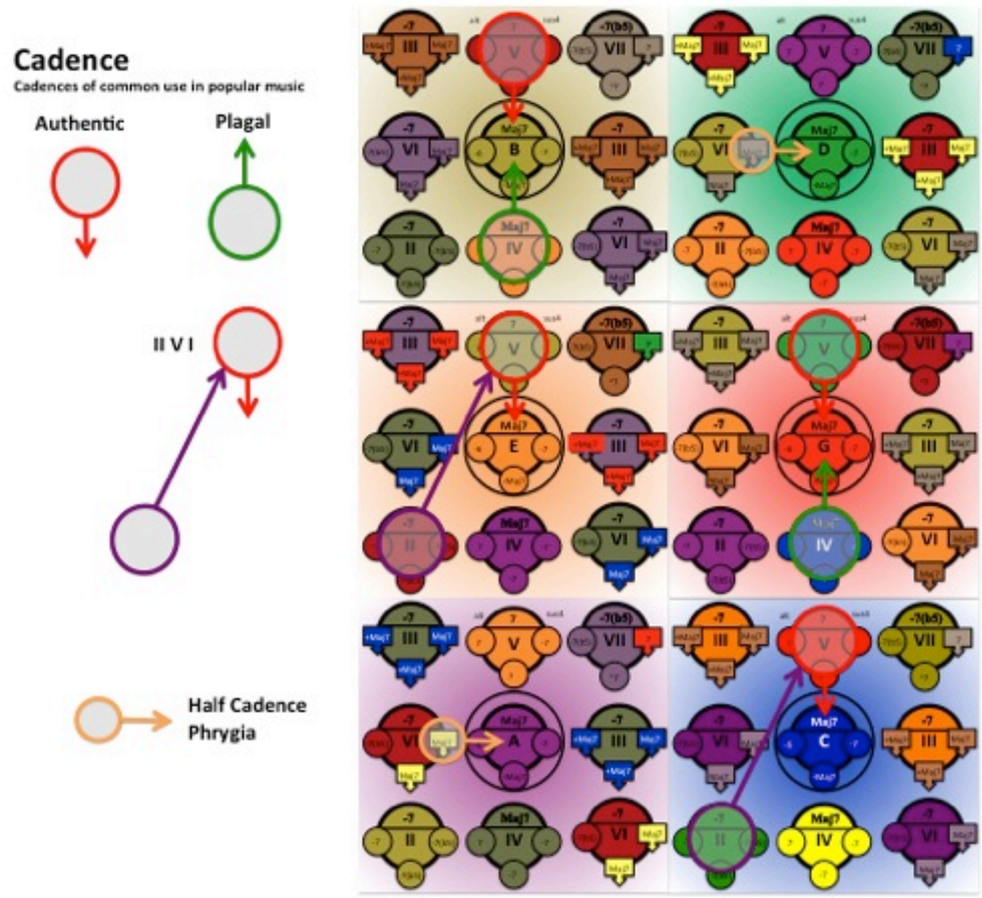


Illustration 29. Initial graphical representation proposed for the tonal map

Discussion: More theoretical, less practical.

This graphical representation is based on the theoretical models of Lerdahl and Krumhansl. The spatial distribution of tonal regions follows the principle that neighbor regions vary the least in terms of alterations. The main advantages of this representation are

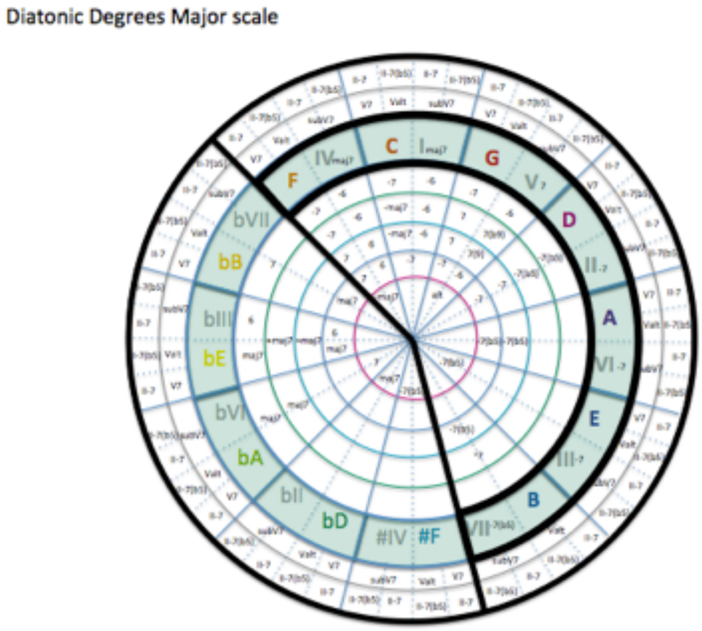
- Possibility to show many tonal regions simultaneously. This is very practical to show modulations or movements between different tonal regions.
- The color code used to represent the root of each chord helps to find common chords within different regions, hence allowing the user to find alternatives in the construction of chord progressions.
- The template shapes can be used as a superimposed layer that suggests, in a graphical way, different alternatives for harmonic movement.

The main disadvantage of this representation is that it requires too much space to show a single tonal region. Additionally, there are many other possibilities within the tonality that are not represented. For a practical implementation it might be better to have a more compact representation that allows faster access to the most common options of harmonic movement.

6.2 Proposed Graphical representation 2

After testing the first representation and taking into account the size of most devices thought to navigate the tonal map (Computer screen, Wacom tablet, Ipad) the need for a different graphic representation has raised.

In this new design, the elements that usually exist within a tonal region have priority, including intermodulation and common movements within a single tonal region. The different concepts included in the representation are shown bellow.



Here we can see the diatonic degrees of the major scale. These chords are the most basic components of any tonal model and each one of them is constructed using the notes of the tonality

Illustration 30. Tonal Map: Diatonic degrees of Major scale

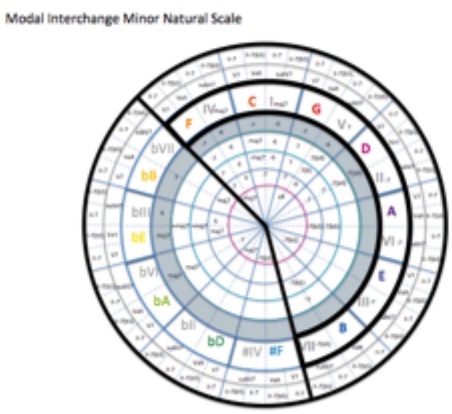


Illustration 31. Tonal map: Intermodulation

INTERMODULATION

The highlighted circle contains the chords that are formed by using the different minor scales.

1) Minor Natural
2) Minor Harmonic
3) Minor Melodic
4) Minor Doric

The empty slots of this circle are chords that don't exist in this mode.

Modal Interchange Minor Harmonic Scale

Modal Interchange Minor Melodic Scale

Modal Interchange Minor Dorian Scale

Non diatonic but common use

COMMON USE:
The most inner circle is used to include some chords hat don't belong to any of the previously mentioned scales but are of common use within the tonality. All of them appear on other tonalities but since they are used frequently they will appear in this

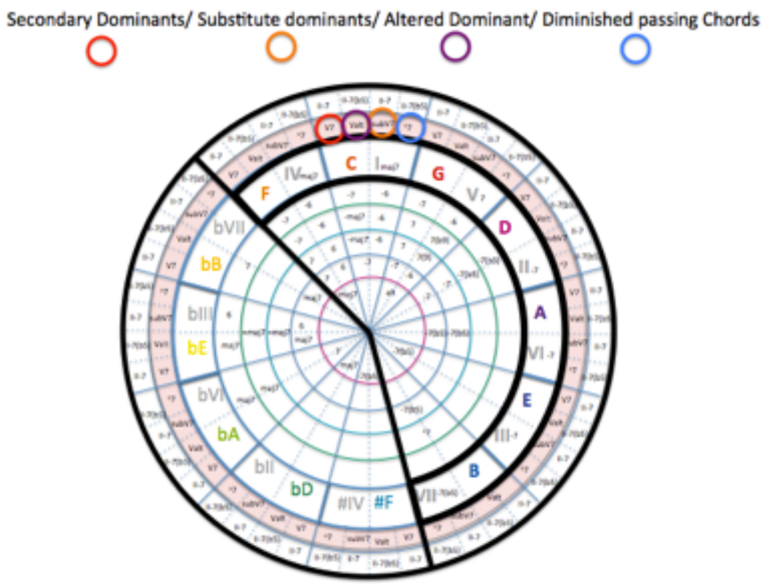


Illustration 32. Tonal Map: Dominant Chords

DOMINANTS:

The highlighted circle contains the different dominants (Secondary, Substitute and altered) and the Diminished passing chorda associated with the diatonic chord that appears on the diatonic circle.

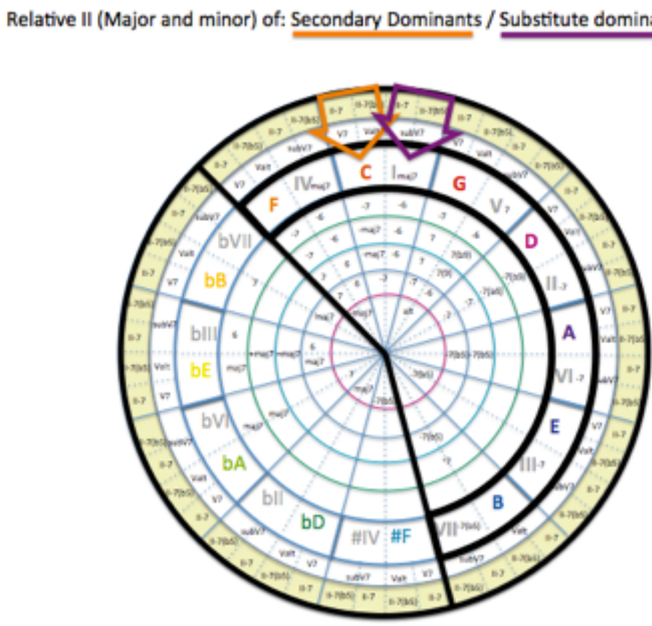


Illustration 33. Tonal Map: Relative II

RELATIVE II

In the highlighted circle are the II degrees relative to both the Secondary dominant and substitute dominants of the Diatonic degree that corresponds to that particular slice. For each of them is possible to use the II-7 for a major target chord and the II-7(b5) for a minor target chord.

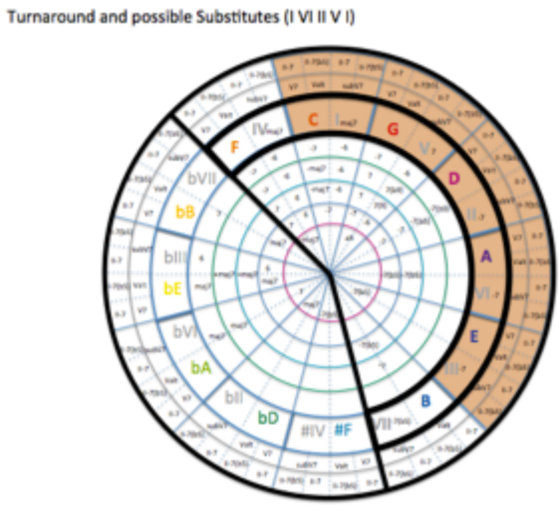


Illustration 34. Tonal map: Turnarounds

TURNAROUNDS:

In the highlighted area appear the elements for the different variations of the commonly used turnaround in jazz and pop music. In the fallowing graphics some possibilities are shown.

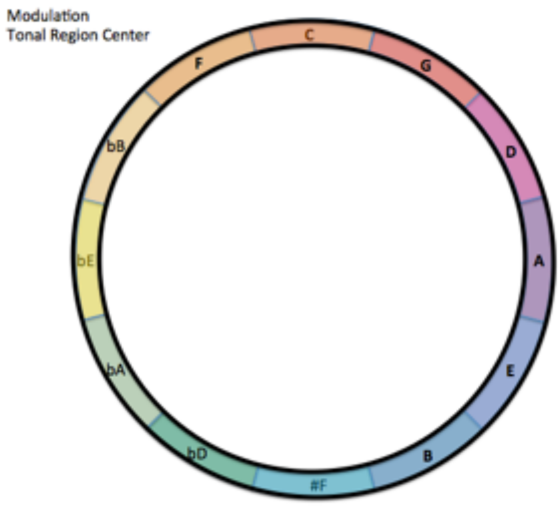


Illustration 35. Tonal map: Modulations

MODULATIONS:

Through this circle one can select a different tonal center. The name of the diatonic degrees change every time the user selects a different tonal region.

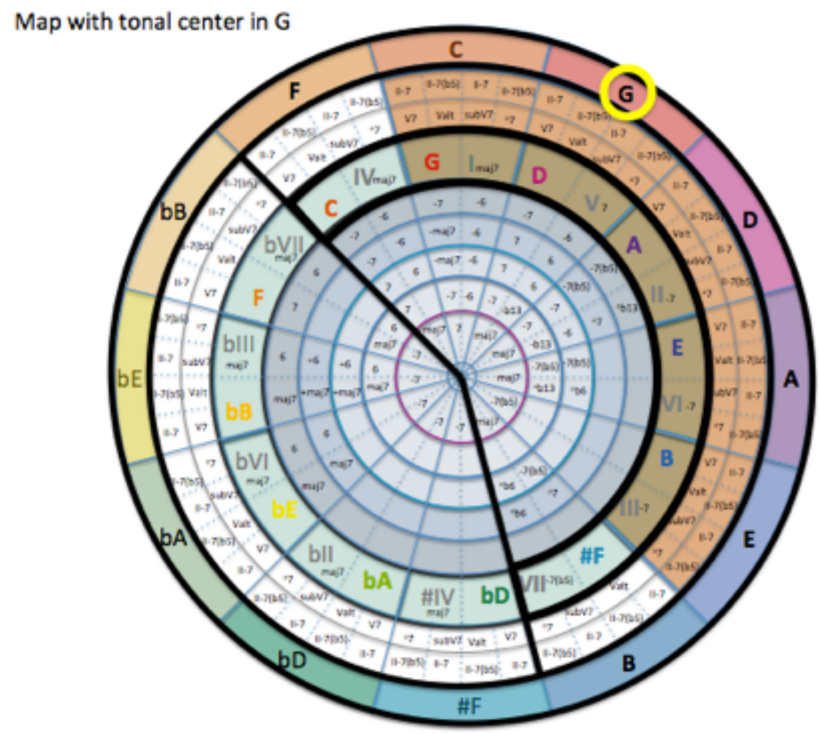
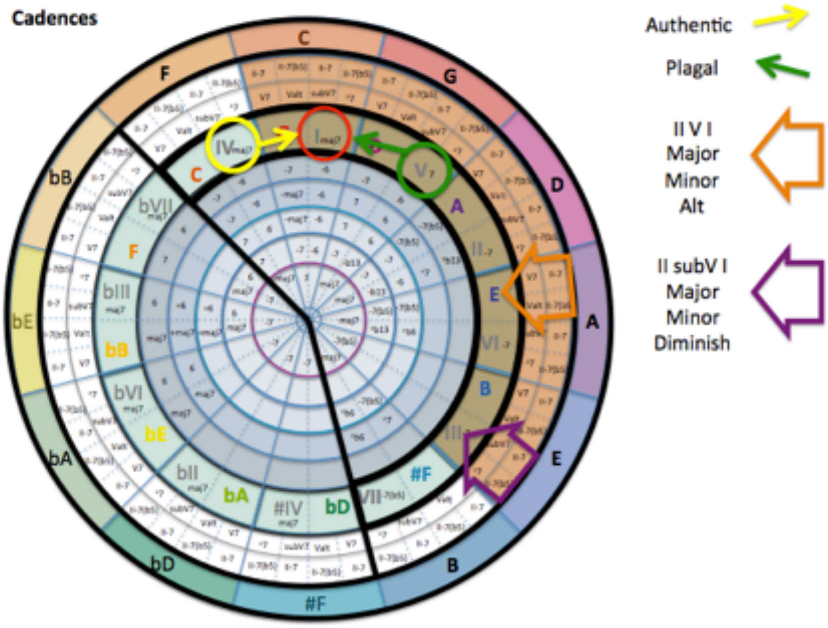


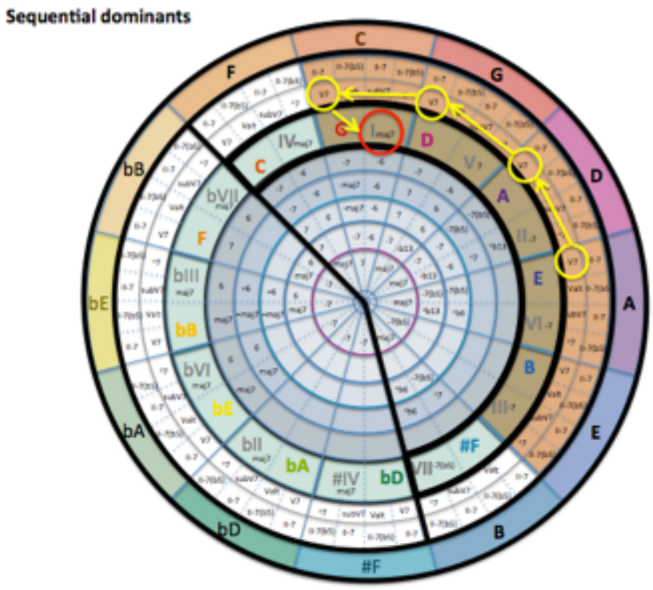
Illustration 36. Tonal map: Whole tonal map center in G

Here we can see the whole tonal Map as it is used in the prototype application



CADENCES: These are the most basic cadences in a tonality. Since their use is very common they have easy access in the interface

Illustration 37. Tonal Map: Cadences



Movement between Dominants:

In the fallowing three graphics we can see different movements between secondary dominants, interpolated dominants, sequential dominants and sequential substitute dominants.

Illustration 38. Tonal Map: Sequential dominants

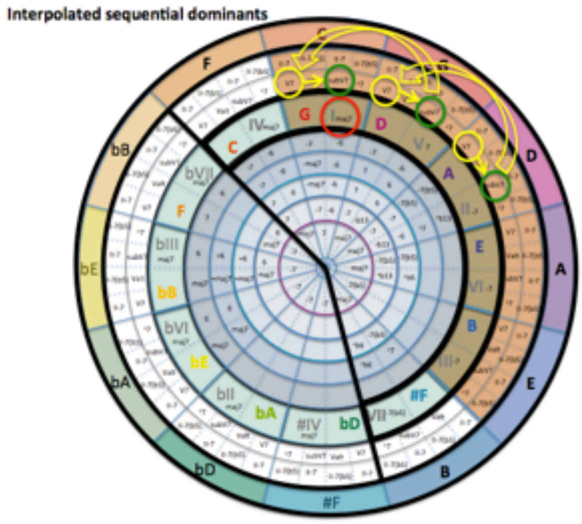
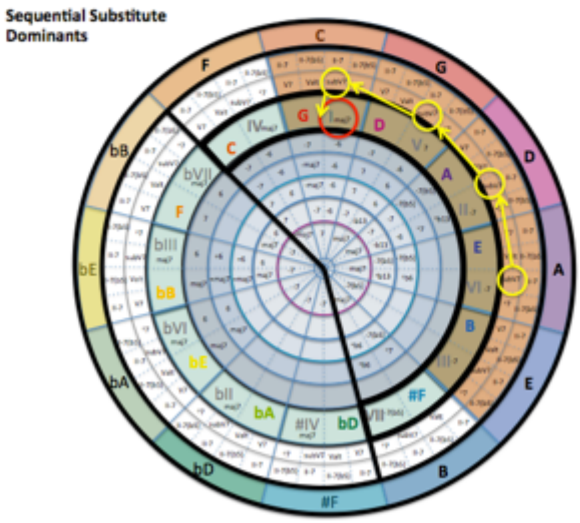


Illustration 39. Tonal maps: Interpolated sequential dominants



Observation:
The shape shown by the yellow circles and arrows can be rotated and the same concept will apply to other target chords

Illustration 40. Tonal map: Sequential substitute dominants

TURAROUNDS:

In this graph the basic turnaround is shown. In the fallowing figures are variations of this structure using chords of similar function and the different dominants.

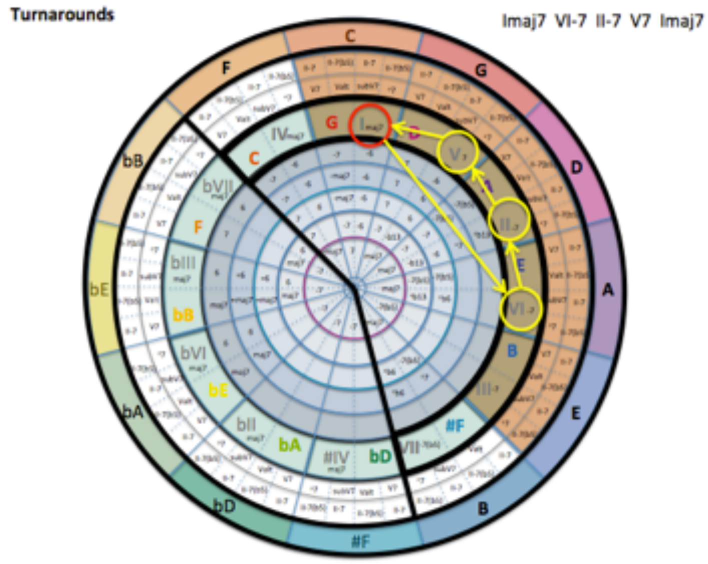
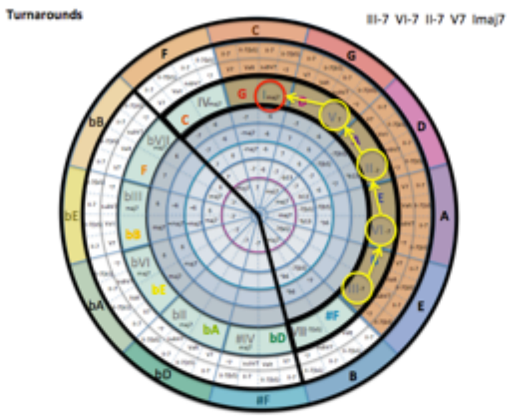
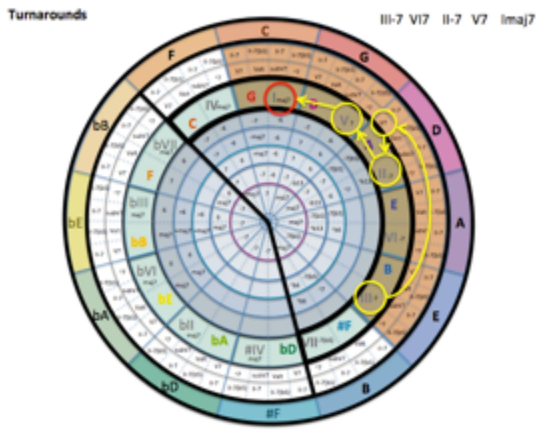
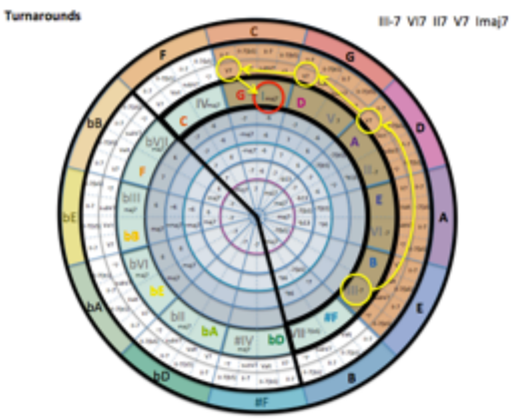
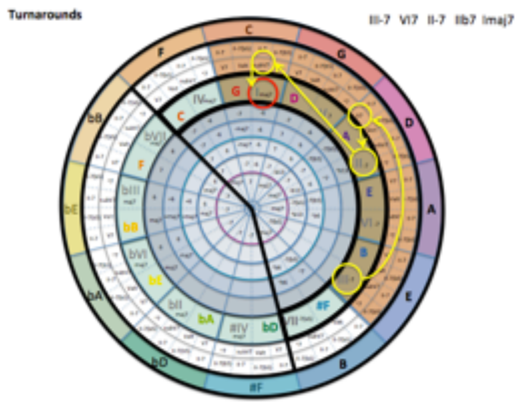


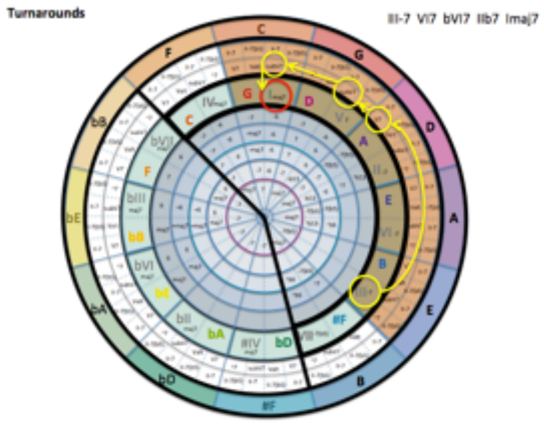
Illustration 41. Tonal map: Turnarounds











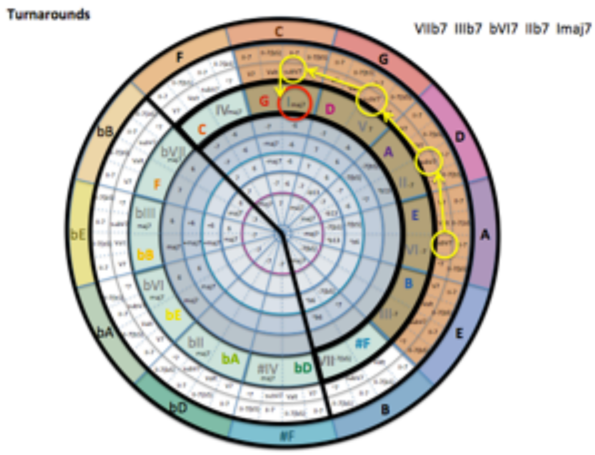
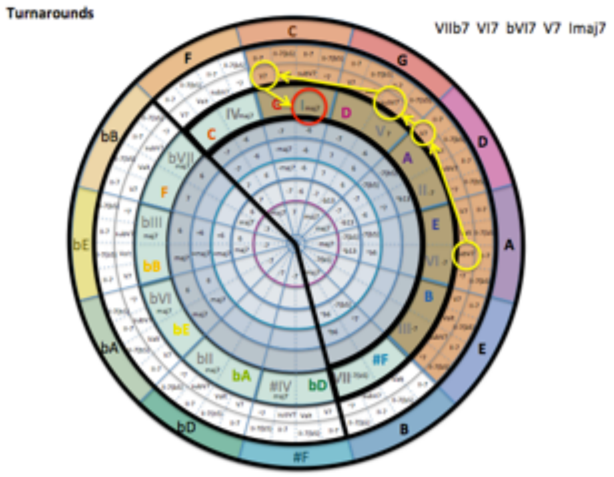
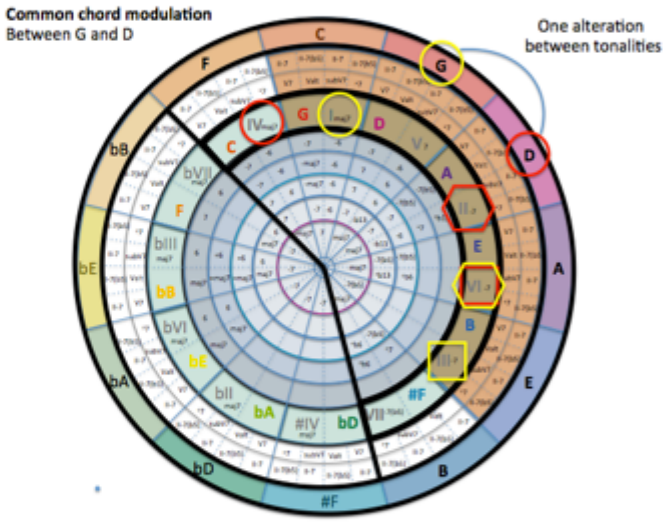


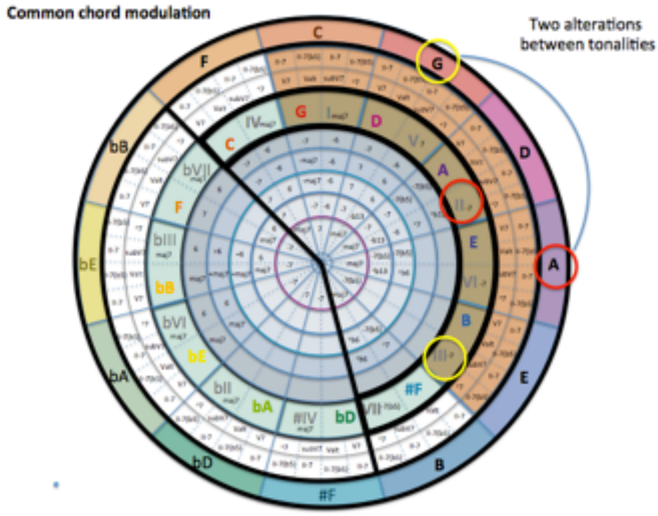
Illustration 42. Tonal Map: Turnaround variations





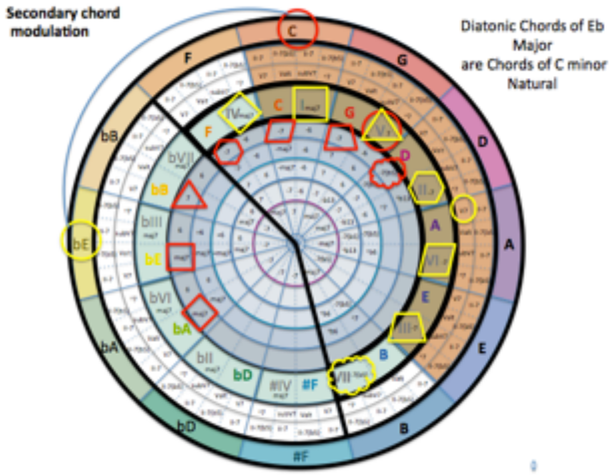
In this graphic, the figures having same shape represent the same chord. The use of different color is to show to which tonal center they are related. This modulation technique can be used between any consecutive elements in the circle of fifths.

Illustration 43. Tonal Map: Common chord modulation, one alteration between tonalities



Between tonalities that are two steps away in the circle of fifths (2 alterations) there is one diatonic chord that is common to both.

Illustration 44. Tonal Map: Common chord modulation, two alterations between tonalities



Secondary chord modulation uses diatonic chords of one tonality that are non diatonic to the other tonality (of an intermodulated version of the other tonality)

Illustration 45. Tonal map: Secondary chord modulation

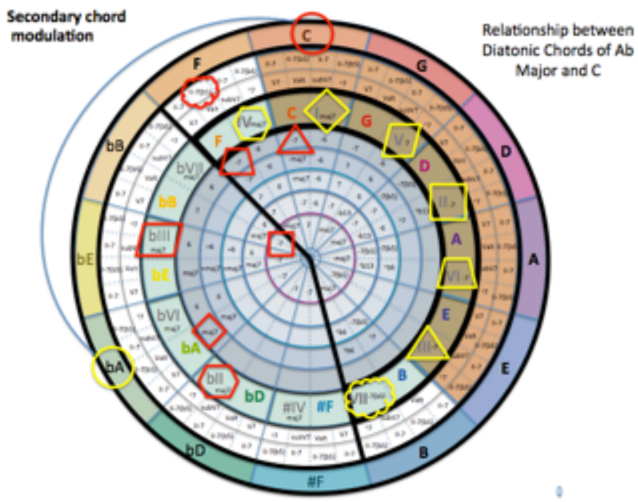
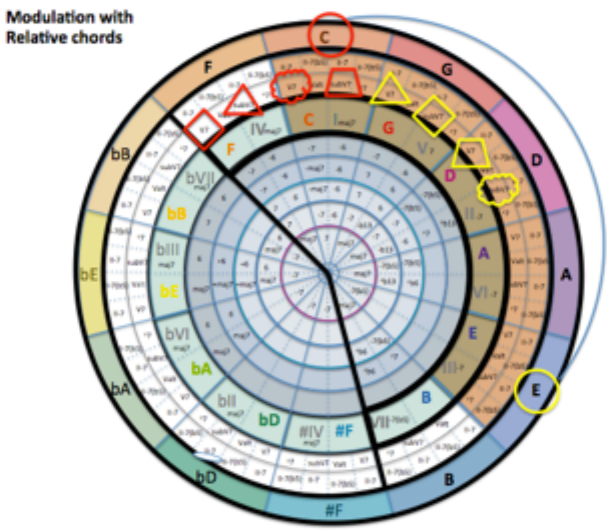


Illustration 46. Tonal map: Secondary chord modulation



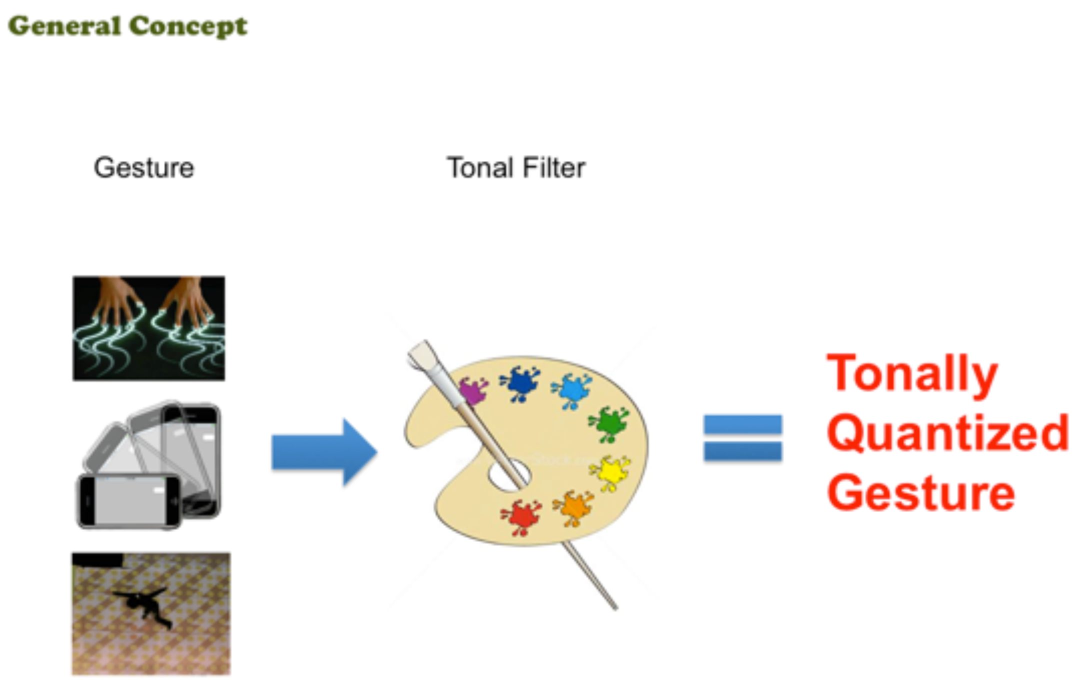
Relative chord modulation uses chords that are non diatonic to any of two tonalities

Illustration 47. Tonal map: Modulation with relative chords

6.3 Prototype patch

After learning and evaluating several programming languages, MAX MSP was chosen for developing the prototype. The MAX for live version allows using the MAX patches as effects or processing modules in Ableton Live, which is a very complete music production environment. Additionally MAX is one of the main software used to develop interactive applications.

The fallowing graphic shows the general concept of the application. As one can see there are two main stages; gesture acquisition and transformation of this data based on tonal graphic representation.



6.3.1 Patch Design

As it was mentioned before, the patch in MAX is used as a MIDI effect within Ableton Live. The patch can communicate with other MAX patches inside the session. Since its possible to use the tonal filter on several tracks at the same time, there is a Master track (the one that is used to navigate the tonal map) and then the slave tracks which have the control data (MIDI Clips, Arpeggiators, Wii, Electronic Drum set, keyboard, etc.), a copy of the Master patch to filter each track and finally the VST instrument that is used to produce the sound.

Illustration 48. Patch Design: MAX for live MIDI plugin window

In the fallowing graphic the different modules of the MAX patch are shown.

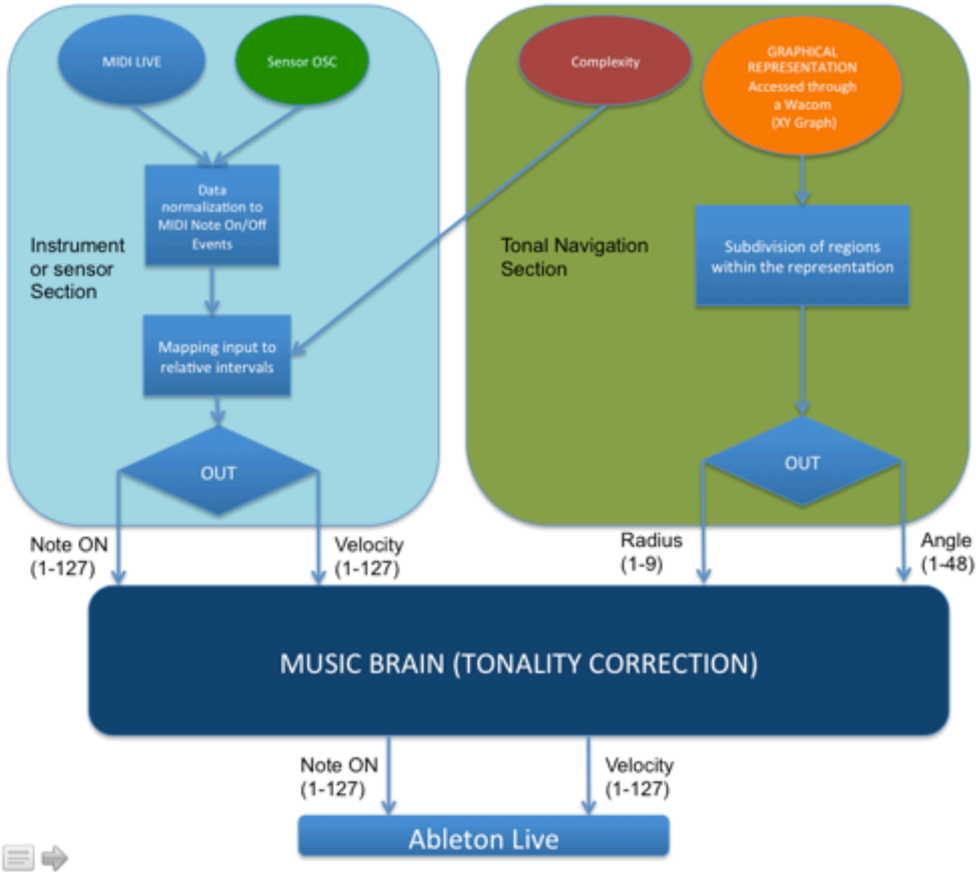


Illustration 49. Patch design: Main components of the patch

Blue Section: On the upper left section is the instrument or sensor input, which handles all the connection with instruments, sensors, or any MIDI inputs arriving to the patch and using this to generate MIDI note events as its output. The complexity variable that crosses between the green section and the blue section sets the constraints regarding complexity of the MIDI stream that will be generated (possible notes to be triggered: Guide notes, triads, tetrads, tensions, scale of the chord, etc.). These MIDI note events represent intervals from the root of the chord that is selected in the tonal map.

Green Section: On the upper right section is the tonal navigation system, which uses the tonal map to select the different possibilities or "principles" to decide how to modify the put-put of the blue section. The outputs are two variables that inform the "music brain", which sector of the graphic representation is active. The patch divides the circle in 9 radiuses and each one of them in 48 possible angular positions.

Music Brain: This section contains all the knowledge regarding the music knowledge that is used by the patch (all the possible scales used for the different chords, circle of fifths, etc.). The inputs coming from the blue section (MIDI note events representing relative intervals) are than modulated by transposing and correcting intervals according to the correspondent scale. This section is explained in more detail in the fallowing graph.

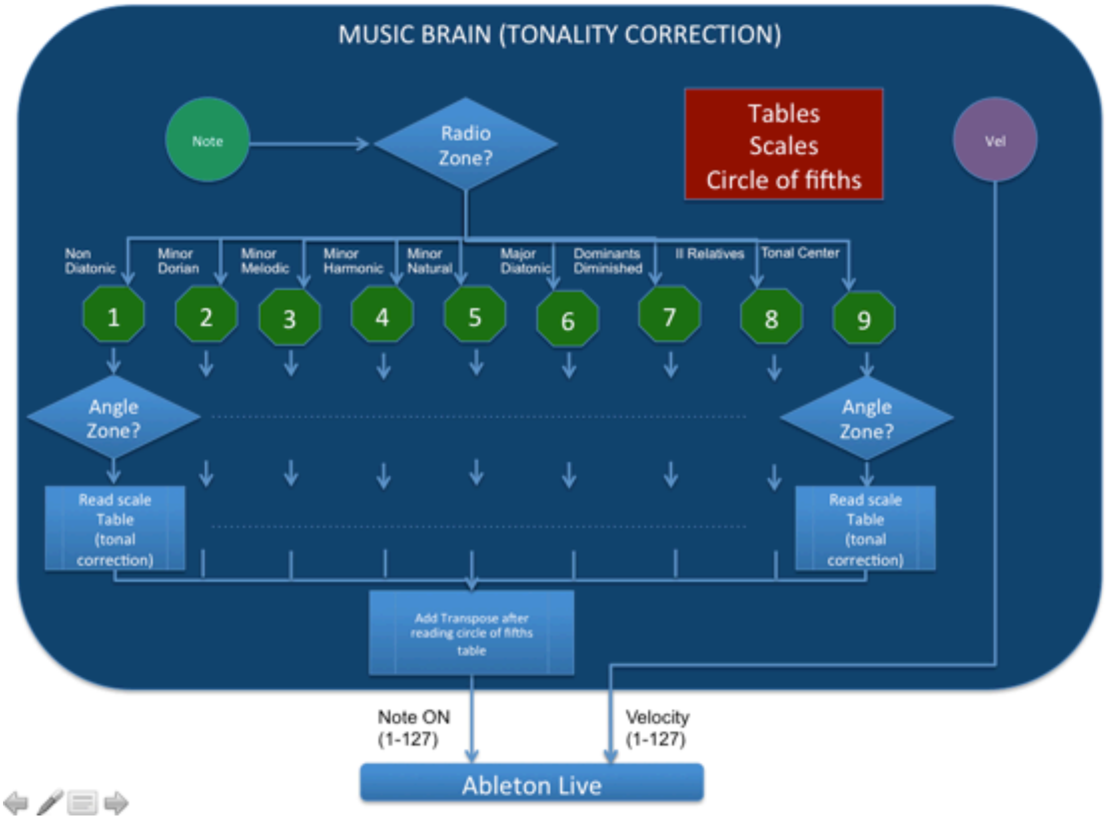


Illustration 50. Patch Design: Tonality correction component

The Midi note number is first routed according to the Radio variable coming from the tonal navigation system. Each Radio represents a different "function" of the tonal navigation (Non Diatonic, Minor Dorian, Minor Melodic, Minor Harmonic, Major Diatonic, Dominant chords and diminished, II relatives and Tonal center for modulations). Once the Note number enters a specific Radio, it is routed according to the angular position in the tonal navigation system. The radius (1 to 9) plus the angle (1-48) will determine the species of the chord, the type of scale (tonality correction) and also the required transposition (Offset based on circle of fifths for each degree of the scale). The note input functions as an index of the scales tables and the output is the "tonally corrected" version of the intervals introduce by the instrument section of the patch (Light blue section of the previous graph)

7 Evaluation

During this project there were two main goals. The first one was to design a graphic representation that included most of the main concepts of tonality used in popular and modern music. The second goal was to implement a system that used this knowledge to manipulate data in real time. For this reason the evaluation process is done stages, one method for the theoretical model and another one for the implementation.

7.1 Evaluation design (Theoretical Model)

7.1.2 Goals of the evaluation

- **Trajectories of chord progressions:** The idea was to determine if it's possible to draw the sequences of chords as a trajectory in the tonal map. To perform this evaluation we will select some songs (popular music and Jazz Standards) and map the trajectories of the chord progressions in the graphical representation. The list of used songs was:

1. Summertime
2. Autumn Leaves
3. Solar
4. Paranoid Android (Radiohead)
5. Knives Out (Radiohead)
6. Blackbird (Beatles)

- **Effect of Chord scale selection:** as it was mentioned before, the scale of the chord is not only a function of its species but also of the tonal function that is performing. To understand the tonal function of a chord is necessary to know where it's coming from and also where it's going. Since our system only takes into account the present chord (has no memory and no prediction feature) we had to choose chord scales that fit better according to the tonality and mode being used. To evaluate if the selection made works well, we will play the song using the system while having another track play the original melody of the song, to see if there are places where the sound is "not correct". This will be a subjective evaluation since we don't have a method to determine the "appropriateness" of this chord scale selection.

7.1.3 Implementation

In the fallowing graphs we will show the analysis of the songs using the graphical representation of the tonal navigation system.

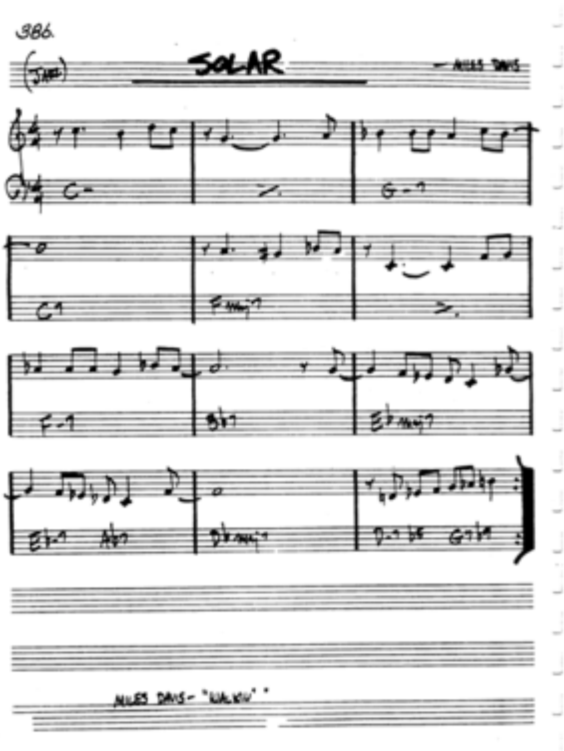


Illustration 51. Evaluation: Solar Music sheet

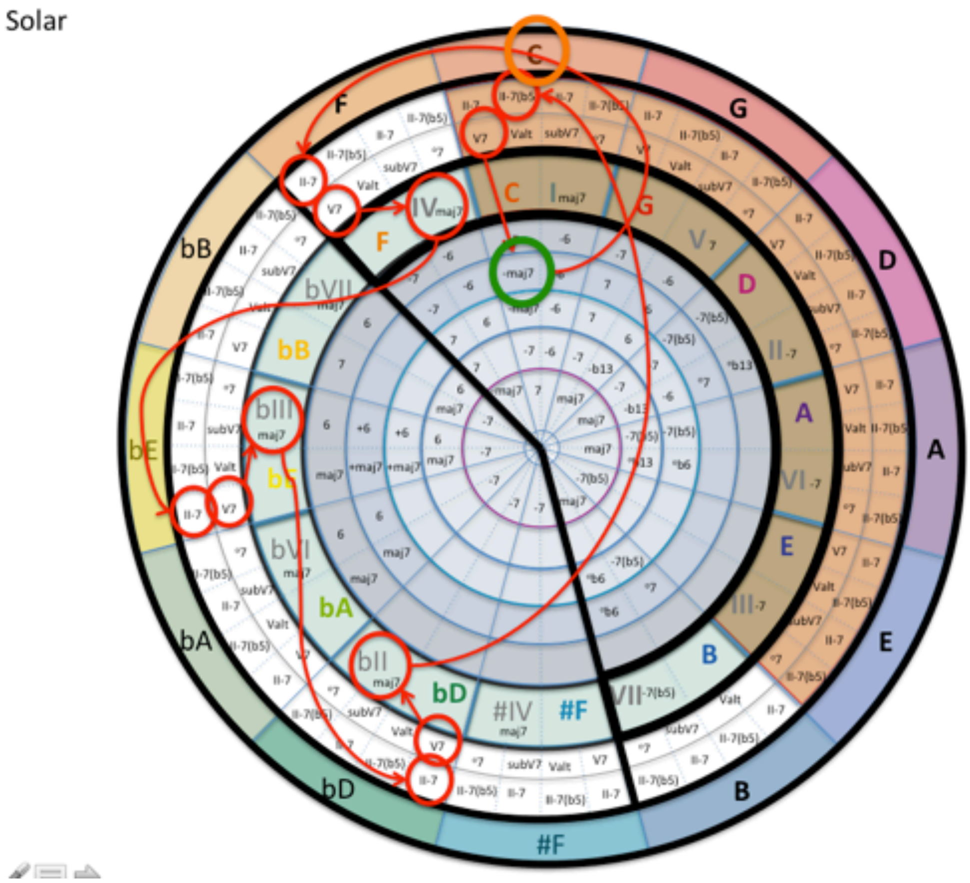


Illustration 52. Evaluation: Trajectories of Solar in Tonal Map

Illustration 53. Evaluation: Autumn Leaves music sheet

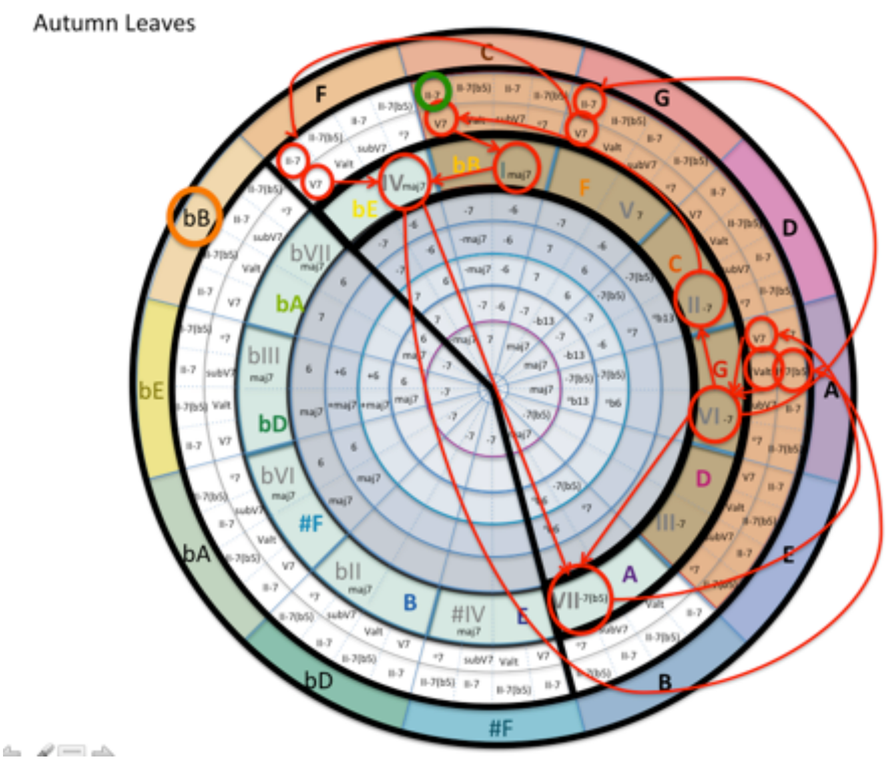


Illustration 54. Evaluation: Trajectories of Autumn Leaves in the tonal map

Illustration 55. Evaluation: Summertime Music sheet

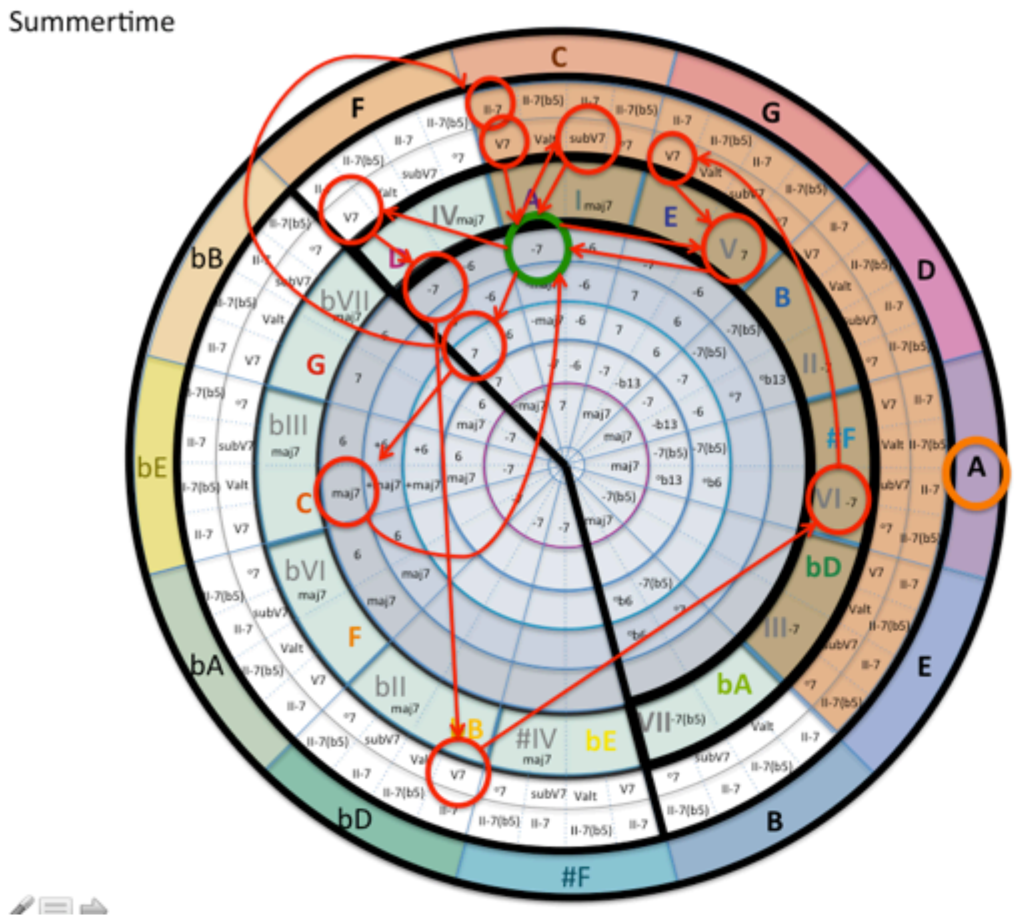


Illustration 56. Evaluation: Trajectories of Summertime in Tonal map

Blackbird (Beatles)

```
INTRO:        | G  Am7  G/B | G*          |


              G          Am7            G/B      G*
VERSE 1:      blackbird singing in the dead of night
              C          C#dim   D       Ebdim     Em   Em(maj7)
              take these broken wings and learn to fly
              D   C#dim  C  Cm  G/B            A7              D7          G
              all your life,    you were only waiting for this moment to arise


LINK 1:       | C  G/B  A7  | D7sus4  G   |


              G          Am7            G/B      G*
VERSE 2:      blackbird singing in the dead of night
              C          C#dim    D      Ebdim     Em   Em(maj7)
              take these sunken eyes and learn to see
              D   C#dim  C  Cm  G/B            A7              D7             G
              all your life,    you were only waiting for this moment to be free


              F   C/E   Dm  C    Bb6  C
BRIDGE 1:     black - bird    fly____
              F   C/E   Dm     Bb6  A7
              black - bird    fly
                        D7sus4              (G)
              into the light of a dark black night


LINK 2:       |(G) Am7  G/B | G*          | C  C#dim  D  Ebdim | Em  Em(maj7) |

              | D  C#dim    | C  Cm       | G/B  A7  D7sus4  G |
```

Illustration 57. Evaluation: Blackbird chords

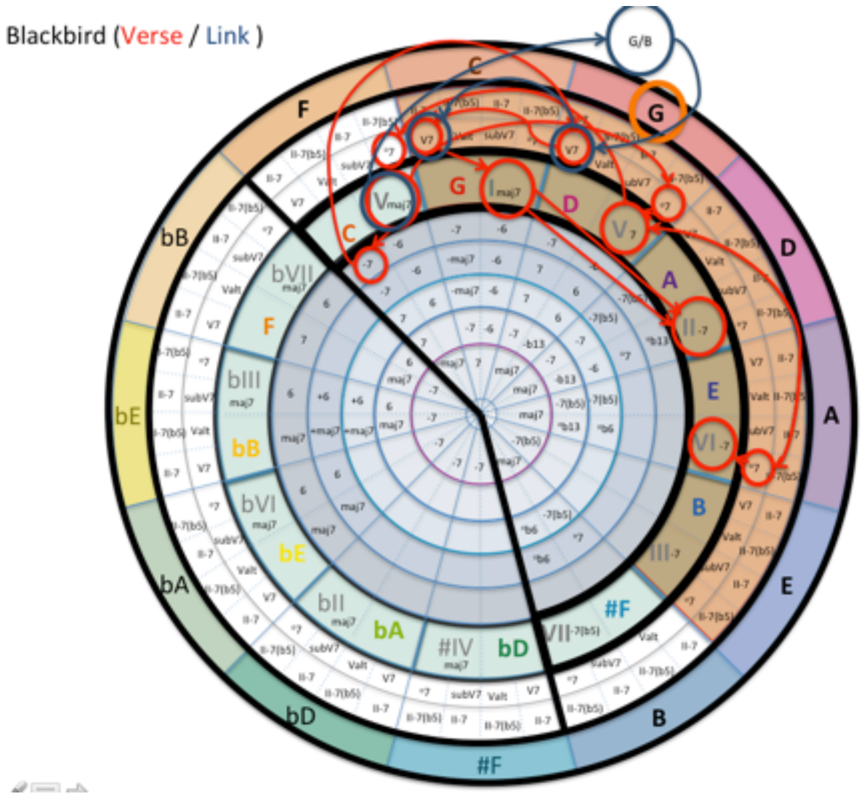


Illustration 58. Evaluation: Trajectories of Blackbird on the Tonal Map

```
              F   C/E    Dm  C     Bb6  C
BRIDGE 2:     black - bird     fly____
              F   C/E    Dm  C  Bb6  A7
              black - bird     fly
                     D7sus4             (G)
              into the light of a dark black night


LINK 3:       | (G)  Am7  G/B | G*     | G      | G      |

              | G   Am7  G/B | C  G/B  A7   | D7sus4 |


              G          Am7            G/B      G*
VERSE 3:      blackbird singing in the dead of night
              C          C#dim    D         Ebdim      Em     Em(maj7)
              take these broken wings and learn to fly
              D   C#dim  C  Cm  G/B          A7             D7           G
              all your life,    you were only waiting for this moment to arise


              C         G/B  A7                D7sus4      G
CODA:         you were only waiting for this moment to arise
              C         G/B  A7                D7sus4      G
              you were only waiting for this moment to arise
```

Illustration 59. Evaluation: Blackbird bridge chords

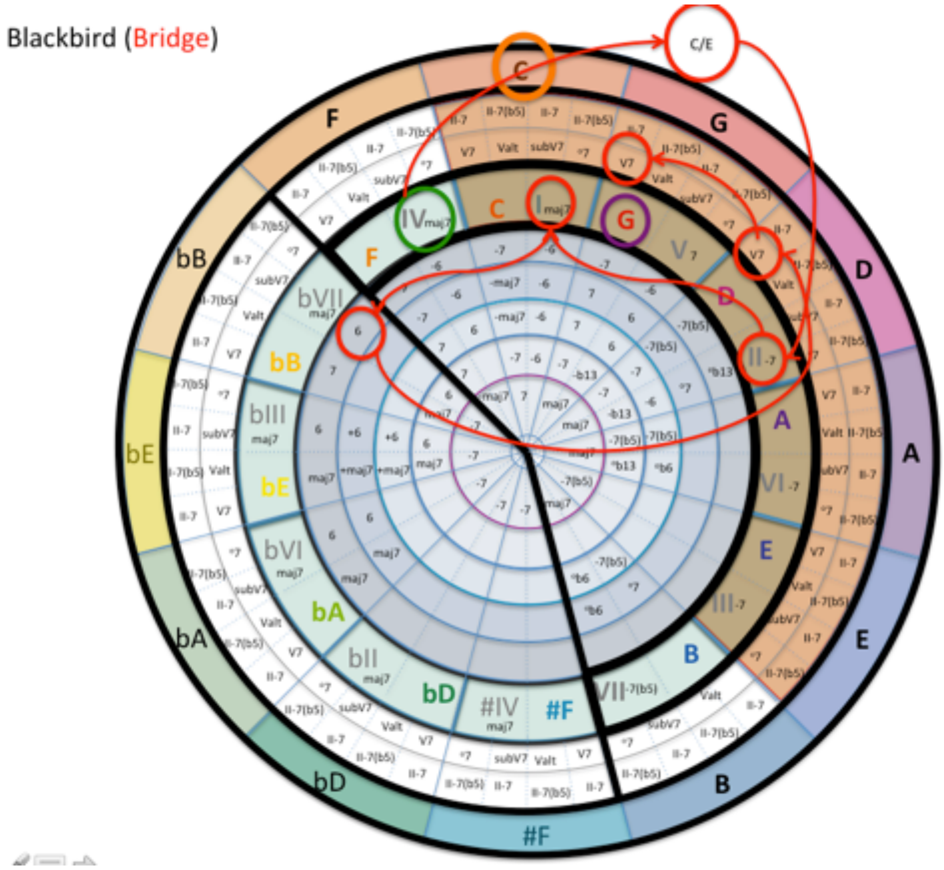


Illustration 60. Evaluation: Trajectories of Blackbird on the tonal map

Knives Out (Radiohead)

```
Intro:
Cm - Bb - Ab
Gm - Dm/F - E6 - E7

  Cm   Bb     Ab
I want you to know
     Gm  Dm/F   Em6    Em7
He's not coming back
Cm     Bb     Ab
Look into my eyes
    Gm  Dm/F   Em6    Em7
I'm not coming back

   Am     A
So knives out
Dm        D7
Catch the mouse
Gm
Don't look down
         Dm/F    Em6     Em7
Shove it in your mouth

   Cm     Bb      Ab
If you'd been a dog
              Gm      Dm/F   Em6    Em7
They would've drowned you at birth
Cm     Bb     Ab
Look into my eyes
         Gm                       Dm/F        Em6    Em7
It's the only way you'll know I'm telling the truth

   Am     A
So knives out
Dm       D7
Cook him up
Gm
Squash his head
        Dm/F   Em6    Em7
Put him in the pot
```

Illustration 61. Evaluation: Kivas out chords

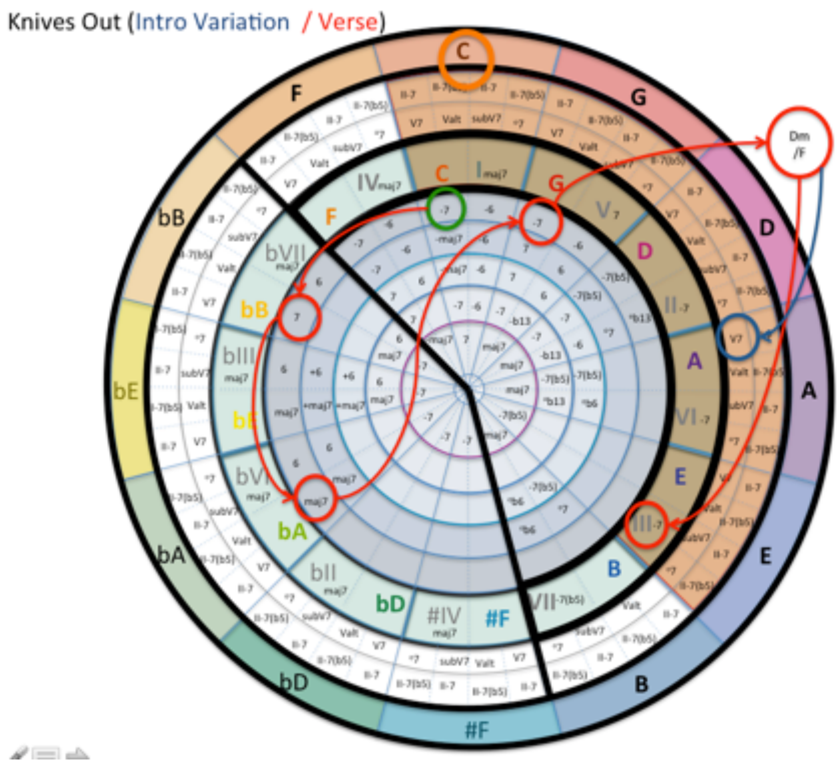


Illustration 62. Evaluation: Trajectories of Knives Out in the tonal map

```
Cm - Bb - Ab
Gm - Dm/F - E6 - E7

  Cm   Bb     Ab
I want you to know
     Gm  Dm/F   Em6    Em7
He's not coming back
     Cm  Bb     Ab
He's bloated and frozen
Gm                        Dm/F             Em6    Em7
Still there's no point in letting it go to waste

   Am     A
So knives out
Dm        D7
Catch the mouse
Gm
Squash his head
        Dm/F   Em6    Em7
Put him in the pot

End in Em6

That's all
```

Illustration 63. Evaluation: Knives out chords

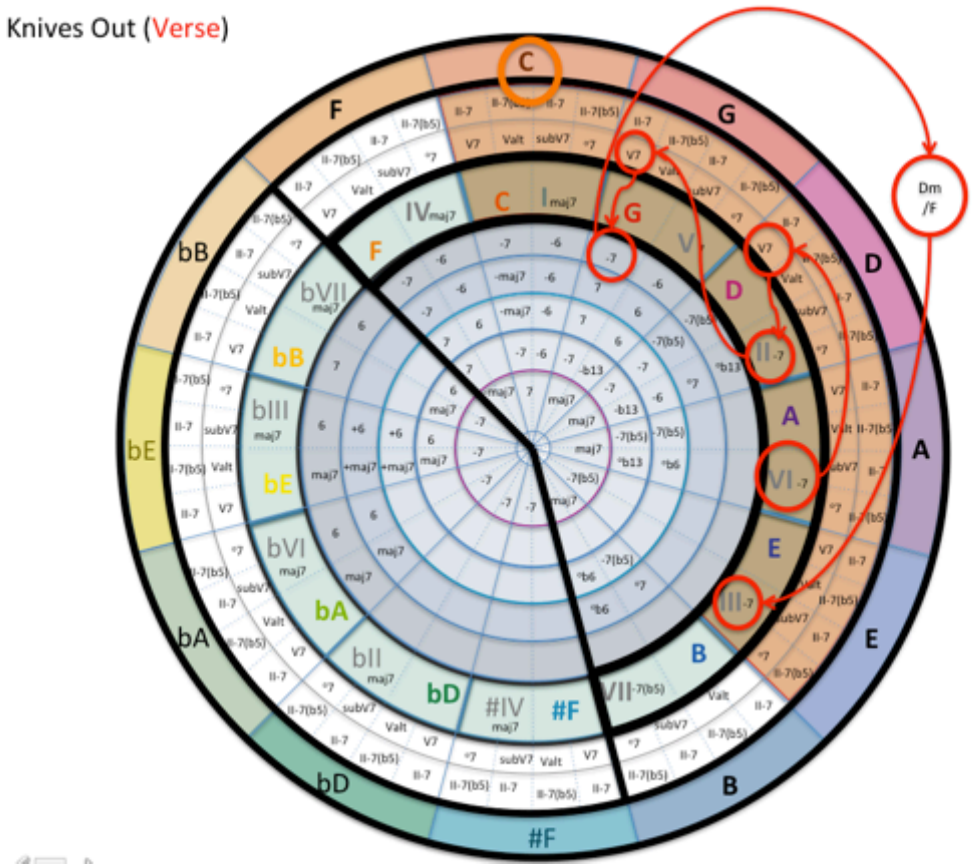


Illustration 64. Evaluation: Trajectories of Knives out in the tonal map

Paranoid Android (Radiohead)

Illustration 65. Evaluation: Paranoid Android music sheet

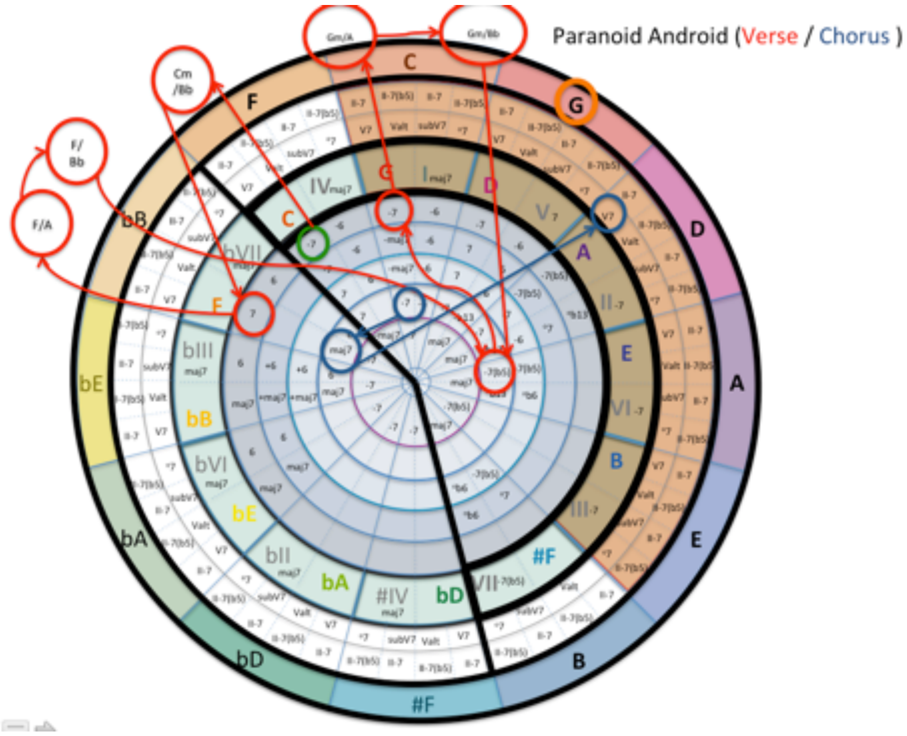


Illustration 66. Evaluation: Paranoid Android trajectories in Tonal Map

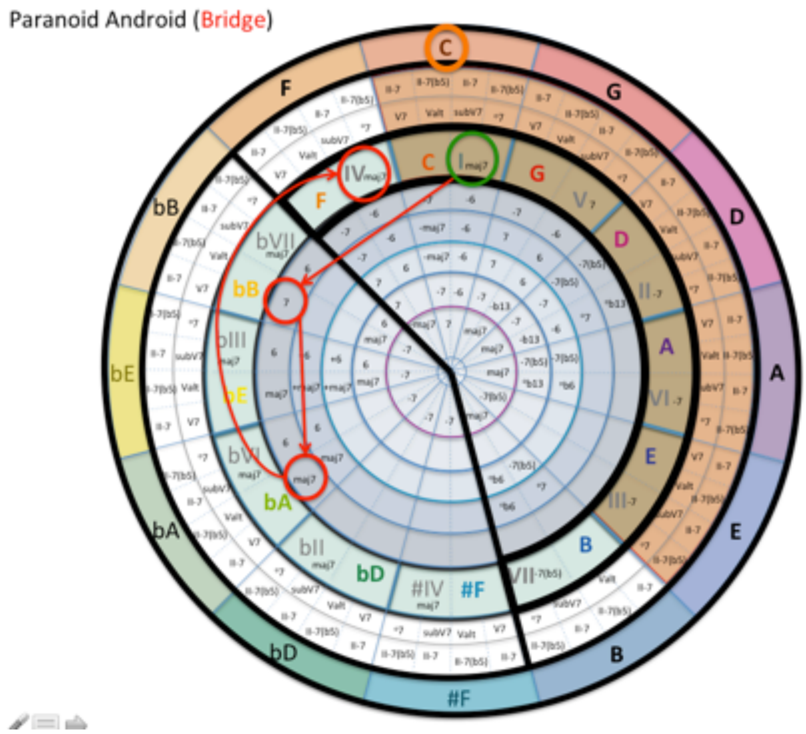


Illustration 67. Evaluation: Paranoid Android trajectories in Tonal Map

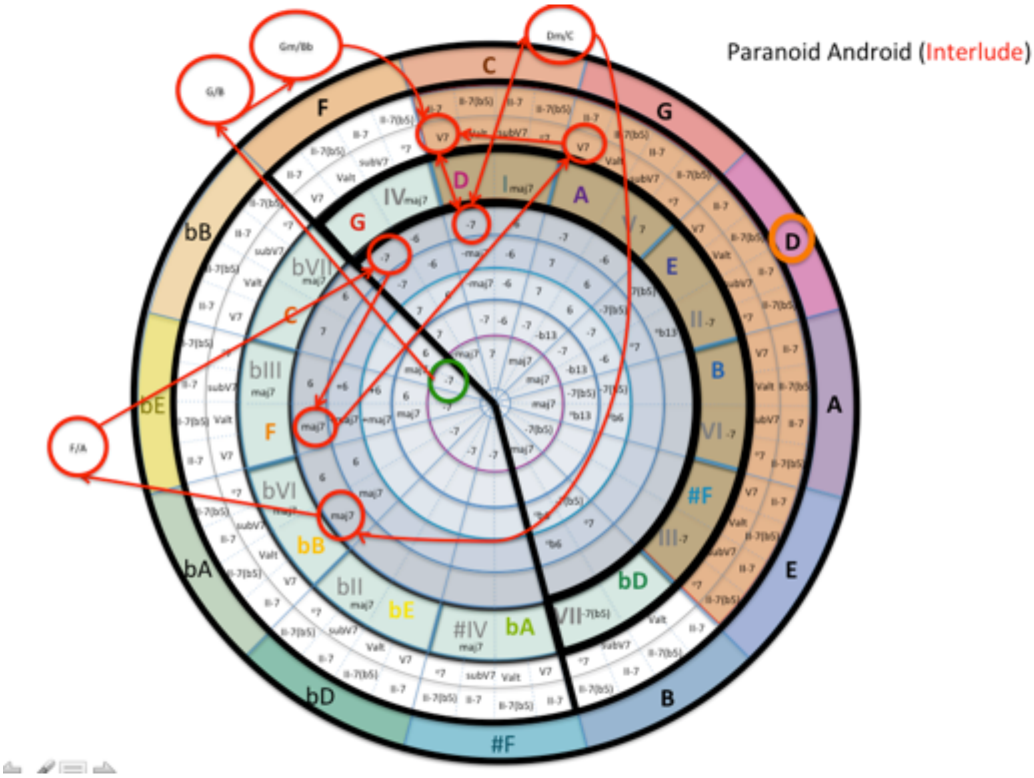


Illustration 68. Evaluation: Paranoid android trajectories on the Tonal Map

7.1.3 Results and analysis

After mapping or drawing several songs over the tonal map we thought it is a tool to analyze songs and how they are structured. Because we don't want to base the analysis on a particular song but rather on the functioning of the whole system we will present a list advantages of our graphical representation a things that could be improve.

Advantages

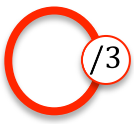
- **Pattern recognition:** the fact that the harmonic movements are translated into a shape characterizing the chord progression allows the user to identify patterns that, when using traditional chord labels, are more difficult to visualize.
- **Functionality of chords:** Because the map was design starting from the functional concepts of tonal harmony it is very interesting to use it to analyze a song. When analyzing a song, sometimes is difficult figure out the origin of each chord. Having this representation of a tonal palette helps to understand the context of the chords being used
- **Reproduction of a song (sheet music feature):** each composition can be written as a shape in the tonal map. During a musical performance, the user could reproduce the song or its elements by navigating the shape of the song with the interactive system. It could be though as a music sheet

that has a guide that allows also non-expert musicians to navigate the song.

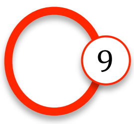
- **"Tonal print" a musical fingerprint:** even though the actual implementation has its limitations, the fact that each song can be translated to a shape could allow creating a sort of fingerprint for the tonal descriptor of a song.

Things to improve or compromises made for the interactive application:

- **Chord Inversions:** It is not possible to specify chord inversions in the tonal map. During the performance the user could still decide which is the voicing used for each chord but through the input generated by the MIDI instrument. In the case of using the system for only theoretical analysis, the nomenclature could be the same circle but with a number specifying the chord inversion. So for example instead of having a chord like G/B we could just have a circle over G with a 1 on it, expressing that is the first inversion of the chord.



- **Complexity of shapes:** when a song has many chords the shapes start to get too complex. An option to solve this problem would be to divide the different sections of the song into different tonal maps. In the case of the interactive application it would be easy to switch the skins to have access to the different shapes.
- **Missing chords:** from all the analyzed songs there was only one chord missing in the tonal representation (The III-maj7). Never the less, many others could appear when analyzing different music styles This chord is not obtained from any of the modes used in the representation. At the moment in our representation there is only one option per degree to select a chord that is not obtained through any of the modes. Another sector of the tonal map could be used for "non tonal chords".
- **Chord tensions:** The tensions of a chord are not specified on the tonal map but rather on the MIDI input that it receives (In the case of the interactive system). It was intentionally designed in this way to give the performer of the instrument the freedom to select the tensions. For analysis purposes the tensions could be written down as a number in the circular shape surrounding the chord. For example, to specify a chord with the 9^{th} we could use this:



- **Triad Chords:** The use of the seventh when forming a chord is not determined by the tonal map but rather on the MIDI input that it receives. The decision to play simple triads is made in the instrument rather than in the tonal filter. It was thought this way to maximize the possibilities within the representation.

7.2 Evaluation design (Patch implementation)

7.2.1 Goals of the evaluation

- **Mapping strategies:** Create different mapping strategies for Wii Controllers and Electronic Drum sets and have users discuss which configuration made them fill more confortable.
- **Quality control test**: over all the different sectors of the tonal representation to ensure that the system is filtering values correctly.
- **Usability in MIDI sessions:** one of the main applications of the system is to have a MIDI live set (composition based on MIDI loops on the session view) and use the tonal navigation system to modulate and tonally quantize several tracks at the same time. A composition based on 4 tracks and 4 loops for each was made to evaluate how well the system works with different tracks and also what's is the musical effect of this type of performance.

7.2.2 Implementation

Mapping: Wii controller

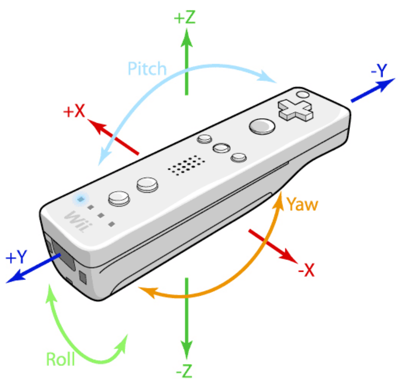


Illustration 69. Mappings of Wii Controller

Strategy 1: (Direct interval trigger)

Pitch: Pitch
Roll: Volume
Up: Complexity (Triad Chord)
Down: Complexity (Seventh Chord)
Left: Complexity (Scale of the chord)
Right: Complexity (Guide notes)
A: Trigger Tonic

B: Trigger Fifth
Minus (-): Trigger Third
Plus (+): Trigger Seventh
Home: Trigger note determined by Pitch value on 16th note pattern
One (1): Reduce pitch range One octave
Two (2): Increment pitch ranges One octave

Strategy 2: (Rhythmic interval trigger)

Pitch: Pitch
Roll: Volume
Up: Complexity (Triad Chord)
Down: Complexity (Seventh Chord)
Left: Complexity (Scale of the chord)
Right: Complexity (Guide notes)
A: Trigger at 16th note the value determined by pitch variable
B: Trigger 16th note triplets the value determined by pitch variable
Minus (-): Trigger at 8th note the value determined by pitch variable
Plus (+): Trigger 8th note triplets the value determined by pitch variable
Home: Trigger at quarter note the value determined by pitch variable
One (1): Reduce pitch range one octave
Two (2): Increment pitch ranges one octave

Mapping: Electronic Drum set

Illustration 70. Electronic drum set Mappings

Strategy 1: (Absolute mapping of intervals)

In this case we use absolute intervals for each element of the drum set. This means that if there are no changes in the tonal map, the same note will be always triggered each element of the drum set (Because the same interval is sent to the system)

Kick: Tonic
Snare: third
Snare Rim: fifth
High Tom: Third + 1 octave
Mid Tom: Fifth + 1 octave
Low Tom: Tonic – 1 octave
HI Hat pedal: Seventh
HI Hat bell open: Tonic + 1 octave
HI Hat bell close: Tonic + 2 octaves
HI Hat edge open: Sixth
HI Hat edge close: Sixths + 1 octave
Crash bell: Ninth
Crash edge: Sharp ninth
Ride Bell: Flat fifth
Ride edge: Sharp fifth

Strategy 2: (Absolute + Relative mapping)

In this strategy the lower part of the drum set (Kick, snare, low tom and HI hat pedal) triggers always the same intervals but the upper part of the drum set (High and mid toms, HI hat and cymbals) add or subtract intervals to the last one played by the "absolute" part of the drum set. So if the last element triggered was the kick, the intervals specified for the "relative" elements of the drum set

Kick: Tonic
Snare: third
Snare Rim: Seventh
High Tom: + 6 semitones
Mid Tom: - 6 semitones
Low Tom: Tonic – 1 octave
HI Hat pedal: Fifth
HI Hat bell open: + 1 semitone
HI Hat bell close: - 1 semitone
HI Hat edge open: + 2 semitones
HI Hat edge close: - 2 semitones
Crash bell: + 4 semitones
Crash edge: - 4 semitones
Ride Bell: + 8 semitones
Ride edge: - 8 semitones

Usability in MIDI sessions

The fallowing graph shows the MIDI composition structure made for our tonal navigation system. Only one MIDI clip per track can be played at the same time but clips from different tracks can be combined in any order because the tonal system will still tonally quantize the output. Three users tried the system by triggering different slots with MIDI clips and using the tonal navigation system at the same time.

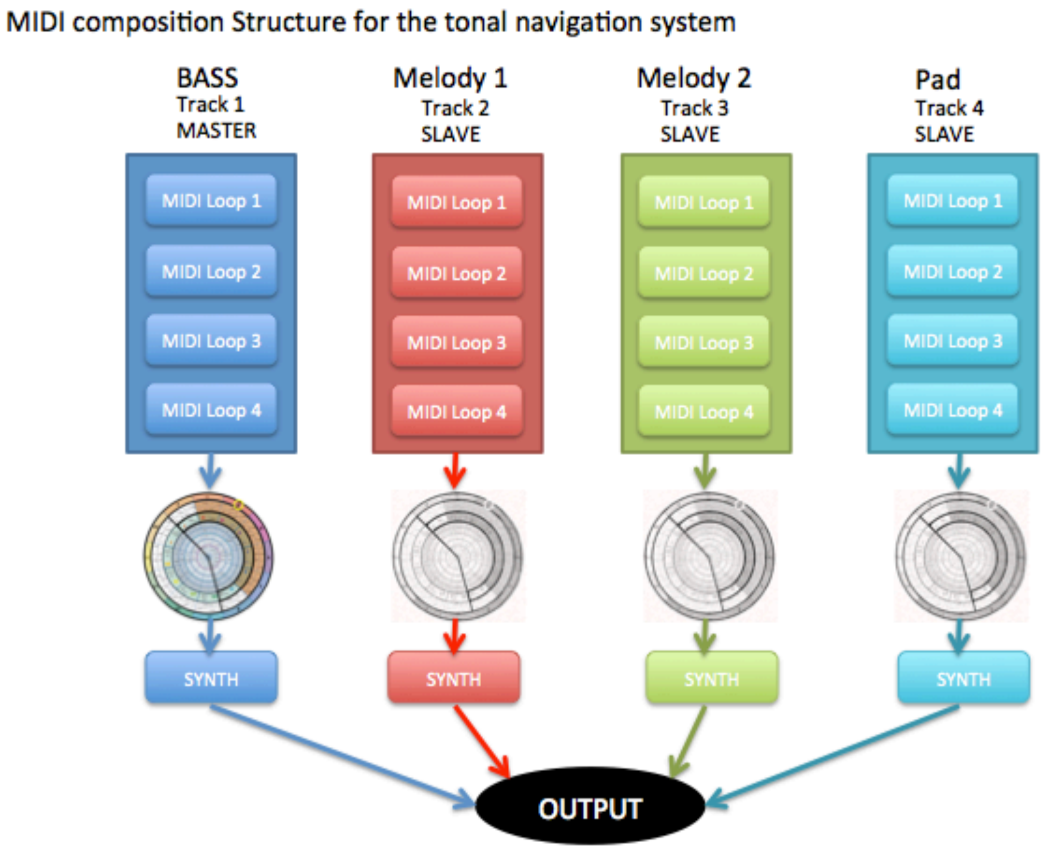


Illustration 71. Structure of MIDI Loop session in Ableton Live

7.2.3 Results and analysis

Mapping strategies (Wii Controller)

After playing for 15 minutes with each configuration for the mapping of the Wii controller, the subjects were asked about their experience. They mentioned that the main advantage of using the Wii controller was the possibility to use the accelerometers to create pitch contours and volume envelopes. The users said that it was the control was intuitive and fun. Regarding the rhythmic aspect of the two configurations, they preferred the second configuration where they didn't trigger each note individually but instead used different note lengths to sample the value determined by the pitch and volume accelerometers. They said that because of the latency it was difficult to keep the rhythm.

Mapping strategies (Electronic Drum set)

After playing for 20 minutes with each configuration for the mapping of the electronic drum set, the subjects were asked about their experience. The main advantage mentioned by the users was the possibility of creating complex rhythmic patterns and also the dynamic range produce by the sensors in the drums. The complex patterns were possible due to the "bouncing" properties of the drumsticks, which allow creating a sort of echo for each of the notes. The subjects mentioned that the configuration with absolute values (first configuration) was more static than the one using relative values. The fact that some drum elements allowed to increment or decrement the outputted note by a certain amount of semitones allowed them to create complex and fast melodic phrases.

Usability in MIDI compositions (Live Sets)

The users found very useful this application because it allowed them to multiply the possibilities of recombining and modulating the different MIDI clips of the song. They mentioned that it was also an interesting way to explore possibilities regarding chord progressions and harmonic movement. Due to suggestions of one of the users we recorded the MIDI output of each MIDI track. This made possible that the user could jam using the tonal navigation system and afterwards select the parts of the performance that they liked the most.

8 Conclusions

8.1 Regarding the graphical representation of tonality

- It is possible to create a graphical representation of elements and concepts about tonality. The fact that there is a certain common understanding of how tonal harmony works, makes it possible to organize and structure these concepts in a hierarchical, semantic and functional way.
- The graphic representation of tonality makes it possible to visualize each chord in its harmonic context. Many methods used to learn modern harmony present these concepts in an isolated way. Even though it is not feasible to reduce all the harmonic possibilities to a single graphical representation, this model allows us to understand the big picture of how tonal harmony works.
- The graphical representation of tonality can be a useful tool for performing harmonic analysis of music. When using the tonal map to analyze songs, the chord progressions are shown as trajectories and paths whose shapes represent patterns or tendencies in the harmonic movement of a song.
- Determining the scale of a chord is a very complex process. Due to the space constraints, the graphical representation does not specify which scale could be used for each chord. The scale is usually determined by the function of the chord, which is at the same time dependent on previous and succeeding chords. Therefore when using the tonal map for harmonic analysis, the direction of the trajectory and position of the chord in the map favors the understanding of the function and thus the selection of the "proper scale".
- The tonal map is an efficient graphical interface to have quick access to different scales, chords and tonal regions. Most systems in use today rely on drop down menus that is not efficient for real time use. In this sense the tonal map functions as a harmonic palette where the user can have direct access to most common harmonically related choices.

8.2 Regarding the prototype of the interactive system for assisted tonal navigation

- The prototype of the interactive system for assisted tonal navigation has many possibilities of use because of its capacity to "tonally quantize" MIDI data coming from different sorts of inputs. It takes advantage of the computer's ability to store musical knowledge and make decisions on the fly.
- The prototype allows for the performance of music in a higher level of abstraction based on the selection of the harmonic content rather than the one-to-one control paradigm over pitch used in traditional instruments. It also separates the tasks of selecting and triggering

intervals from the choice of what kind of interval it should be (minor, major, augmented, diminished, etc.).

- The interactive system favors multi-user performances because while many users can be generating MIDI streams using different inputs (MIDI instruments, sensors, Wii controllers, IPhones, etc.), other users can use the tonal map to treat this data so that the output is framed within a tonal context (Tonal region, chord scale, etc.).
- Determining the scale of the chord is a complex process because it depends on the function of the chord. In order to have a more accurate system for selecting the proper scale it would be necessary to take into account previous and succeeding chords. In the case of our prototype scale, selection was based on the scale of each mode, the notes of the chord and in some cases on the function. Because a part of the tonal map was made entirely based on functional concepts (II V I in its different forms and diminished passing chords), the correspondent chord scales of this section were chosen more straightforward (using the standard scales for these progressions). This functional part has some chords that are duplicated in other parts of the map but they use different scales.
- The prototype of the tonal navigation system is a tool for music composition that can produce new types of music. The separation between the macro-control of tonality with the nuances that other sensors can introduce into electronic music performance offer a new technique for making music.
- The use of superimposed shapes over the tonal map is a new way of having a "graphical score" that is easy to follow during performance. In this sense, the user could have a reference to reproduce a song but would still be free to make any variations or improvisation during performance.

9 Future work

To finish this report we will propose some aspects of the graphic representation and implementation that can be improved.

9.1 Improvements of graphical representation

- Implement the graphical representation in a tangible interface that is able to show more information as additional layers over the tonal map. The tonal map is a good base from which upon to show different concepts through superimposed layers.
- Create a database for stylistic suggestions that are shown afterwards during performance through superimposed translucent layers over the map. For example, after analyzing and drawing trajectories of several songs from one band, this information could be used as a suggestion system. Every time the user selects a region of the map the system could suggest possible succeeding chords. This can be applied to any particular band or music genres.
- Create a system to store chord progressions after a performance or also through drag and drop of regions. The actual prototype has no memory or capability of storing the performance on the tonal map. Adding this feature could be great for musical performance (Similar to the technique used in the Harmonic Improvisator)
- Add a feature that allows the user to set the amount of information shown in the tonal map. For initial users the entire information of the tonal map might be saturating. A slider could be implemented to gradually increase or reduce the amount of concepts shown in the graphic interface. This will help to adjust the complexity of the system to the users knowledge of the system.
- Add one disc in the representation that is for user defined chord and scale. In this area of the tonal map users could customize the map to their own music styles while still having the rest of the standard palette of possibilities

9.2 Improvements of the interactive system

- Add new input sources to the system. One of the most interesting things of this interactive system is that it opens a wide range of possibilities to use different types of sensors to create music. Some of them could be: Kinect, Video input, Wii controllers, Guitar Hero and video game controllers.
- Implement the system in a more robust architecture such as Ipads or any other tablets. This will allow the user to navigate the tonal map in a more confortable way making possible to zoom, show additional layers as for example the suggestion system, scale selection, etc.

- Implement the system as a VST plugin that functions as a MIDI effect. Most of the actual sequencer software doesn't have a way to dynamically modulate MIDI clips but instead they rely on drop down menus with not many possibilities.
- Implement the system as an interactive installation.

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