Interaction with tonal pitch spaces

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ABSTRACT
In this paper, we present a pitch space based musical interface approach. A pitch space arranges tones in a way that meaningful tone combinations can be easily generated. Using a touch sensitive surface or a 3D-Joystick a player can move through the pitch space and create the desired sound by selecting tones. The more optimal the tones are geometrically arranged, the less control parameters are required to move through the space and to select the desired pitches. For this the quality of pitch space based musical interfaces depends on two factors: 1. the way how the tones are organized within the pitch space and 2. the way how the parameters of a given controller are used to move through the space and to select pitches. This paper presents a musical interface based on a tonal pitch space derived from a four dimensional model found by the music psychologists [11], [2]. The proposed pitch space particularly eases the creation of tonal harmonic music. Simultaneously it outlines music psychological and theoretical principles of music.

Keywords
Pitch space, musical interface, Carol L. Krumhansl, music psychology, music theory, western tonal music, 3D tonality model, spiral of thirds, 3D, Hardware controller, Symmetry model

1. INTRODUCTION
To make the process of music creation more intuitive it is necessary to find interfaces that are easy to understand and intuitive to play. The interfaces should provide many musical possibilities that can be accessed by a small and expressive parameter set. They also should represent music psychological, physical and theoretical principles. The goal of the musical interface presented here is to bring together results of the pitch space research on the one side and the possibilities of recent developments in the area of controllers on the other side. For this we will first give an overview of the state of the art in pitch space research and then we will show how such pitch spaces can be combined with hardware controllers to form new musical interfaces.

2. TONAL PITCH SPACE
The description of musical tonality with geometrical models has a long tradition. Early approaches are for example Heinichen's (1728) or Kellner's (1737) regional circles, the harmonic network proposed by Leonhard Euler (1739), and Weber's (1767) regional chart [3]. Known as circle of fifths (Kellner's regional circle), Riemann's "Tonnetz" (Euler's harmonic network) or Schönberg's chart of key regions (Webers regional chart), these models are of great interest till this day. In the meantime, advanced geometric tonality models have been developed. Roger Shepard [4] proposes several helix models, which primarily describe aspects of octave equivalence or fifths and chroma proximity. Elaine Chew [1] proposes a so called Spiral Array. The model's core is the, harmonic network inspired, geometric arrangement of pitches on a spiral. The great breakthrough of Chew's model is a unified description of the relationship between tones, chords and keys within one model and the observation of functional relationships that build a tonal center. Fred Lerdahl's [3] "diatonic space" consists of "basic space", "chordal space" and regional space". These spaces help to model different aspects of tonality. There are many other ideas for representing musical aspects geometrically, e.g. Dmitri Tymoczko "orbifold space" [5], Aline Honingh's idea to describe and visualize the principle of shapeliness of tonal pitch structures.

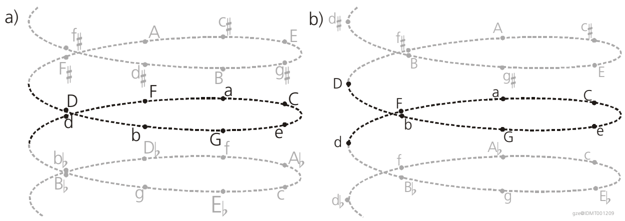

Figure 1. The spiral of thirds: a) The direct derivation from Krumhansl's 4D MDS Sapce [6]; b) An adapted version as basis of the proposed musical interface approach

3. THE APPLIED PITCH SPACE
3.1 Derivation
The musical interface approach presented here uses a geometric pitch space which has been derived from Carol L. Krumhansl and E. J. Kessler's four dimensional multidimensional scaling solution [6]. The pitch space is part of a larger framework of pitch spaces called *symmetry model* [12][13]. The space used here is a three dimensional spiral which's ends close in the fourth dimension (Figure 1a). Cutting out one spiral winding results in a subspace which contains 8 tones that form a diatonic set (Figure 2a+b). The

start and the end of the spiral winding are formed by the same tone. *If the pitch space is modified* such that these two pitch classes occupy the same XY-location (see Figure 2c, Figure 1b) it is possible to represent many basic tonal relationships by *simple geometric structures or in simple geometric ratios (*Table 1). That simplification again makes it much easier to navigate and find desired tonal structures within the pitch space.

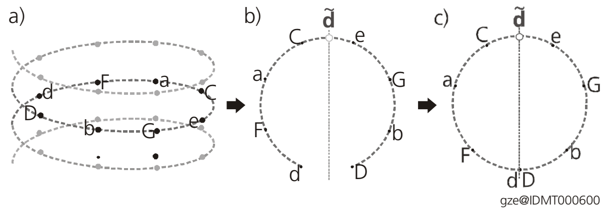

Figure 2. The extraction of one spiral winding results in a 2D subspace that represents a diatonic key. This 2D space is the basis of the proposed interface [6]

Representing one extracted and modified spiral winding in a 2D plane – like shown in Figure 2 – results in a new geometric sub pitch space which particularly expresses key related tonal structures like functional relationships, aspects of tension and resolution as well relationships between tones, intervals and chords [6]. This expressivity led to the decision to develop a musical interface based on the adapted Krumhansl space.

Table 1. Often used tone combinations and its position

Diatonic Key	One complete spiral winding
Maj/min. chord	Three neighbored tones
Relative minor	Direct neighbor counter clockwise of major
Relative major	Direct neighbor clockwise of the minor chord
Parallel major	The cord located directly one spiral winding above a given minor chord
Parallel minor	The chord located directly one spiral winding below a given major chord
Diminished	The tones forming the start and the end of the selected spiral winding
Major/minor sevens chord	Four neighbored tones (G-b-D-F)
Subdominant chords	All tones to the left of the symmetry axis (e.g. d-F-a, F-a-C [8]
Tonic chords	Tones centered around the geometric center of the selected spiral (e.g. a-C-e, C-e-G) [8]
Dominant chords	All tones to the right of the symmetry axis (e.g. e-G-b, G-b-D) [8]

3.2 Geometric versus cognitive center

It is important to distinguish between the geometric center and the cognitive center of a key. The *geometric center* is located exactly in the middle of the selected spiral winding (Figure 2, represented by the tilted d). The geometric center is the same for all diatonic keys (major, minor, …). To be aware about the geometric center helps to recognize redundancies in western tonal music. An example: The chord progression C-f-C has exactly the same geometric structure like the chord progression a-E-a. But both structures are mirrored around the geometric center of the key. There are much more of such major/minor mirror relationships which become apparent when the pitch space is aligned to the geometric center. But from a music psychological point of view the geometric center is not the tonic of a key. The tonic of a key is represented by the root of the given key which we denote with *cognitive center*. The most resting tone in a given key is that root note. While the geometric center of a key is mode independent the cognitive center of a key changes if the mode changes. For this it could be better to align the pitch space not to the geometric center but to the appropriate root note. This is shown in Figure 3: Figure 3a shows the system aligned to the geometric center. It can be seen that major and minor chords together form a perfect symmetric structure. It should be noted, that the geometric distances along the spiral correspond to the tones distances on a semitone scale. Figure 3b shows the system aligned to the cognitive center of a-Minor. The root note "a" is represented on the circle's top. The root of the subdominant ("d") and the root of the dominant ("g") are now symmetrically arranged around the tonic. Figure 3c shows this for C-Major: The root "C" is aligned to the circle's top, the subdominant ("F") and the dominant ("G") are symmetrically arranged around the tonic ("C"). To make a musical interface intuitive it should allow switching between the two alignment types. It should be possible to change the alignment between the major tonic, the minor tonic and key's geometric center.

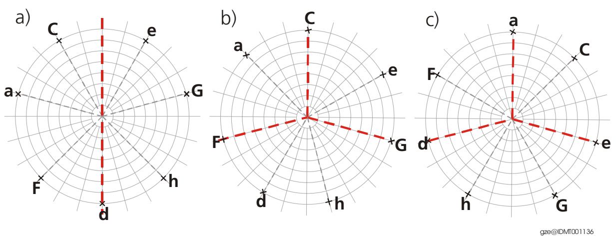

Figure 3. The difference between a key's geometric center and a key's cognitive center: a) The geometric center, b) the major root and c) the minor root are represented on the top

4. NAVIGATION IN PITCH SPACE

Now we will derive an interface that makes it possible to select parts of the pitch space like the one described in Table 1. Firstly a simple set of parameters will be chosen in order to define the desired sound. The interface proposed here has to support the following movements and tasks in pitch space:

a) Moving within one spiral winding to play tones and chords of one key. If the selected spiral winding is projected onto a 2D plane like shown in figure 2 this results in a 2D navigation.

b) Define what pitches are selected if a certain spatial position has been reached. This requires parameters that define the dimensions of the selected part in the space.

c) Change the current spiral winding to change the key or to temporarily play chords from other keys. This results in a movement within the 3rd dimension.

d) According to Figure 3 it must be possible to align the pitch space to the major tonic or to the minor tonic or to the geometric center of a given key. The alignment should be a task which is executed conscious.

4.1 Playing Tones and Chords - Navigating within one spiral winding

The most basic task to create music is to navigate within one spiral winding and to select tones of one key. In Figure 4 it is shown that concrete pitch classes are represented at discrete angles. But to make pitch classes audible we also have to assign a pitch height to every pitch class. For this the authors propose to use the radial dimension to assign different root positions to every pitch class. According to Figure 4 this results in four control parameters for playing tones, intervals and chords: 1.) A start angle, 2.) an apex angle 3.) a start radius and 4.) an apex radius. The *start angle* defines the root of the chord that is to be played (Figure 5). The *apex angle* defines how many pitch classes neighboured to the root are played (Figure 6). The *start radius* it used to define the pitch height of the played pitch class such that the pitch height increases continuously with the radial position. So the higher a tone's pitch the greater is the tone's radial position. Because chords can also be composed of tones of more then one octave the *apex radius* can be used to increase or decrease the number of octaves that are used to generate the tone combination.

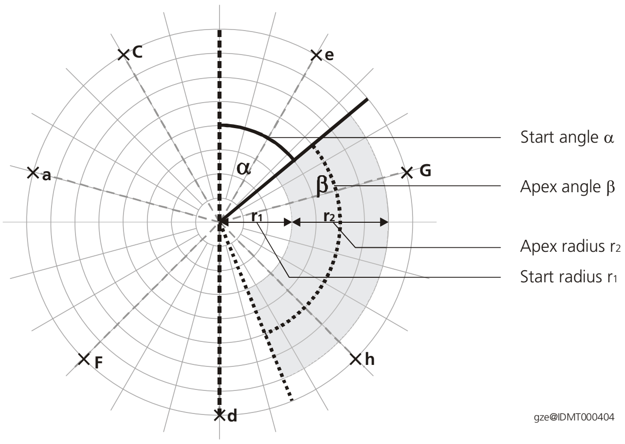

Figure 4. The selection of tones in the pitch space is done using only 4 parameters

In order to fade between tones, intervals and chords as well as to fade chords continuously from one into another, a spatial tone distribution function is added to every tone. This distribution function describes what happens if a spatial part between two tones is selected. So by *moving the pitch selection in radial direction* the pitch height of the chord can be transformed (Figure 7). This again allows to create inversions of a given chord. *By moving the selection in tangential direction* neighbored chords can be crossfaded. Continuous increase of the apex radius results in brighter chords, continuous increase of the apex angle results in a continuous fading between single tones, third intervals, major and minor chords or major or minor seven chords.

4.2 Changing the key - Changing the spiral winding

It has to be distinguished between two modes of spiral winding change: 1.) the *permanent key change*, which is used, if the key shall be modified permanently. This permanent modification is used for example, if another song shall be accompanied or the current musical piece is to be transposed. In that case it is necessary to switch to another spiral winding and also to rotate the spiral winding such that the geometric or cognitive center (Section 3.2) is represented at the same position where the former key's center was represented. In Figure 3 this position is the circle's top.

2.) The second change is the *temporary key change*: In many cases there is a fixed key, but we need to play chords that belong to another diatonic set. E.g. often it is required to play the dominant major chord in harmonic minor. In that case it is necessary to jump to another spiral winding, but the tonal center shall remain at the same spatial location.

Table 2. Several key respectively spiral winding changes:

	Key change	Spiral winding change
1	Jump to the parallel major key	Select the spiral winding directly above the current one
2	Jump to the parallel minor key	Select the spiral winding directly below the current one
3	Shift the key by one semitone	Shift the spiral by fife fifths
4	Jump to the next key in the circle of fifths	Shift the spiral by one fifths to the left or to the right

Table 2 shows characteristic key changes. The two most important spiral winding changes are the parallel major/minor ones (Table 2: 1, 2). These changes convert a given major chord to a minor chord and convert a given minor chord to a major chord (See also Figure 1). It can be seen that these changes are simple operations. Other operations like the transformation of a given major chord into the dominant 7th chord are more complicated and have to be regarded in more detail.

Figure 5. Example 1: The change of the start angle allows to play different chords. From left to right: The chords F-major, C-major and G-Major. Note: To identify the correct pitch class labels look to Figure 2c.

Figure 6. Example 2: A continues increase of the apex angle makes it possible to fade between single tones, third intervals and major or minor chords

Figure 7. Example 3: A continuous movement of the selected area allows the genera-tion of mixed chords like the dominant 7th.

5. THE HARDWARE CONTROLLER

To execute the tasks described before, several hardware controllers have been subject of experiment. The subsequent chapter describes the use of a 3DConnexion SpaceNavigator. The 3DConnexion Space Navigator is a 3D Joystick that provides 6 degrees-of-freedom: a) Move left/right, b) push/pull, c) tilt forward/ backwards, d) rotate, e) tilt left/right, f) move forwards/ backwards (Figure 8).

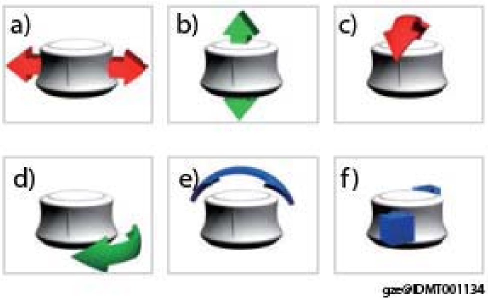

Figure 8. The six degrees of freedom of the 3DConnexion SpaceNavigator [9].

The question is now, how to assign these degrees-of-freedom to the spiral navigation tasks described before. Table 3 proposes a mapping of different tasks to the parameter of the controller.

Table 3. Navigating within the pitch space using the 3DConnexion SpaceNavigator

	Task	Space Navigator
1	Select the start angle	Move cap towards the appropriate angle
2	Select the start radius	Move the cap to the appropriate radius
3	Start playing the selected tones	Stop the movement
4	Define the velocity of the tones	Acceleration of the stop
5	Jump to spiral winding above/below	Push/Pull cap
6	Shift the spiral winding by one fifth to the left or to the right	Twist cap left/right
7	Shift the spiral winding by fife fifths (pm 1 Semitone)	Tilt cap
8	Align the pitch space to a given root note (psychological center)	Physically rotate the whole space navigator
9	Change to a selected key permanently	Select Key (Task 5-8) and press Button B
10	Define apex radius	Button A + Twist cap
11	Define apex angle	Button A + Rotate cap

Tasks 1-4 of Table 3 describe how tones are activated: The start radius and the start angle are defined by moving the SpaceNavigator towards the appropriate point. Stopping this movement triggers the play of the tones, whereas the velocity of the played tones depends on the (negative) acceleration when the movement is stopped. Tasks 5-9 of Table 3 show the realization of key changes that are changes of the selected spiral winding. In western tonal music the most frequently used spiral winding change will be to jump to the spiral winding directly above or directly below the currently selected. According to Table 1 this spiral winding change transforms a given minor chord to its major chord and a given major chord to its minor chord. Analogue to the geometrical movement within the spiral the pull and push function of the SpaceNavigator is proposed to perform this task. For this it is possible to transform e.g. the e-Minor chord to E-Major or the F-Major chord to an f-Minor chord by pulling and pushing the cap. Tasks 6 and 7 propose a mapping of SpaceNavigator functions to other types of key changes. Other key changes than the one described in Table 3 can be generated through combinations of the presented movements e.g. a key change of one whole tone e.g. from C to D can easily be performed by a double tilt or a double twist. With the assignment of spiral movement operations as shown in Table 1 it is possible to execute all of the key changes described in Table 2. It has to be denoted that all key changes performed by Task 5 to 8 are temporary key changes (4.2), i.e. if the cap is pushed and then the parallel minor key is immediately selected. If the cap is released after that, the selection returns to the previous key. This makes it possible to "borrow" chords from other keys easily. To switch to a key permanently the appropriate task of (Task 5 to 8) has to be performed and after that Button B has to be pressed. Task 9 shows that it is easily possible to align the system to the root of a given major or minor key: This can be simply done by rotating the whole SpaceNavigator, so that the desired root note shifts to the SpaceNavigator's top. The required visual feedback can easily realized by positioning the controller on a printout of the pitch space (Figure 9).

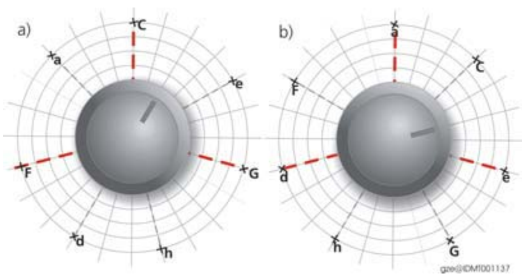

Figure 9. By rotating the whole SpaceNavigator the user can align the system to major or minor: a) C-Major, b) a-Minor

6. SOFTWARE ARCHITECTURE

Figure 10 shows the software architecture that realizes the presented musical interface approach. The core module is the module "Geometric Pitch Distribution". This module defines where the tones are geometrically positioned within the pitch space. In our case this module realizes the spiral of thirds and can be replaced by other geometric pitch distributions, e.g. the circle of fifths or a Riemann network. The module "Pitch Selection" defines in what way pitches can be selected for playout. The Pitch Selection depends on the geometric pitch distribution and provides a high level interface to change e.g. the start- and apex angle or the start- and apex radius (Figure 4) or the velocity of the tones to be played. The control parameters provided by the pitch selection module must be mapped to the parameters of a given hardware controller e.g. the SpaceNavigator. This is done by the "Parameter Mapper". This module receives the events from the hardware controller (SpaceNavigator), transforms those events if required and maps these parameters to the control parameters provided by the module "Pitch Selection".

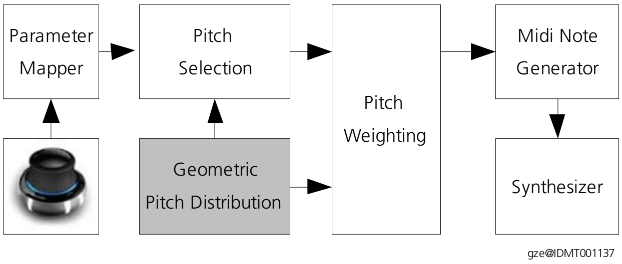

Figure 10. The software architecture of the presented interface approach

The module "Pitch Weighting" takes the current Pitch Selection and the given Geometric Pitch Distribution and derives the weights of the currently selected pitches. The weighted pitches again are forwarded to the "Midi Note Generator" which generates a midi signal which is fed to a synthesizer.

7. EVALUATION

To evaluate the parameter mapping proposed in Table 3 several informal tests, a focus group and a usability test have been conducted. The focus group consisted of five participants of varying musical background. The usability test featured 20 participants (10 musicians, 10 non-musicians). Task 1 (as proposed in Table 3) has been perceived as according to the model in the software, and generally accepted. Due to the self-centering property of the SpaceNavigator, Tasks 2-4 have been evaluated as difficult and only suitable for experimental musical settings. Thus the start radius has preliminarily been set to a fixed position. This led to an alteration of the controller assignment of Tasks 3 and 4 in a way that now a note is being played when a certain radius-margin is being crossed. The velocity of the played note is now derived from the velocity of the movement during the crossing of that margin. Tasks 5-7 have been perceived as very problematic and unusable, due to physical limitations of the SpaceNavigator. It has been found that the 6 degrees of freedom of the SpaceNavigator cannot always be handled simultaneously. For example a full rotation locks the controller cap and prevents movement to the desired angle (as in Task 1, Table 3) etc. Also handling two independent parameters on two different axes led to problems. The reason for this was that manipulating a parameter A involuntarily led to change in another parameter B also. In addition, the simultaneous manipulation of two or more independent parameters has been perceived as very complicated. The manipulation of the apex angle (Table 3, Task 11) has been perceived as totally unusable by more than half of the test persons. This was due to the high sensibility of the SpaceNavigator. Also the time it takes to set the angle has been rated to be too long for real musical applications. Some people stated that they liked the perceptional link to the pitch space and the way that notes are being selected and played (parameter 1, Table 3).

8. APPLICATIONS

The proposed pitch space based musical interface is interesting for different target groups. *Children* often have extensive skills in computer games and the usage of new hardware controllers. Such an interface could help them to learn tonal western music step by step. Combined with an appropriate visualization they can quickly learn many theoretical relationships like the composition of chords, functional relationships between chords (subdominant, tonic, dominant) or relationships between different keys, but also more psychophysical relationships like the distinction between pitch chroma (assigned to angle) and pitch height (assigned to radius) which have been shown to be processed in different brain regions [10].

Music students often have to learn many music theoretical terms. For them it is important to keep the overview. The challenge within this relationship is to bridge the gap between theoretical knowledge and its practical application. Using a pitch space based instrument could help them to organize many theoretical terms by linking them to a spatial model. The possibility to interact directly with such geometric representation of tones and to hear the result immediately will additionally help them to improve their learning progress. For this the proposed musical interface could become part of the standard scholar education.

Older people are often willing to learn a new instrument, but classical instruments like piano or violin are too complicated and require the development of extensive motor functions. A musical instrument with a simple set of parameters could motivate them to start a new challenge i.e. to start to learn a new instrument.

Musicians, DJs, Composers: Combined with an advanced sound synthesis (Figure 10) the pitch space based instrument can become a creative tool that supports the finding of new chord progressions throughout all keys and to develop advanced sound textures.

9. SUMMARY AND RESULT

A new musical interface approach based on tonal pitch spaces was presented. The approach targets both musicians as well non musicians. The combination of tonal pitch spaces with 3D-Navigation tasks and a real-time auralisation provides many new musical possibilities. The used model was derived from a music psychological model which guarantees a strong relationship between the used model of tonality and cognitive principals. With the extraction of one spiral winding and the projection onto a XY-plane a strong simplification of the tonal space and the complexity of navigation tasks could be reached (Figure 2). The alignment of that diatonic subspace to the symmetry axis respectively the geometric center of the extracted key helped to encounter structural redundancies between major and minor which again leads to a reduction of the learning matter.

A simple set of parameters to navigate within the pitch space and to interact with pitches has been provided. This interface allows fading continuously between tones, intervals, chords and inversions of chords as well as defining chord progressions throughout all keys, modulations, etc. The spiral of thirds portions the 12 major and the 12 minor keys in easy understandable diatonic subspaces which can be easily accessed. The spiral has been designed such that important tonal relationships like parallel and relative major and minor chords are in neighborhood.

To create music out of the pitch space several navigation tasks have been defined and mapped to the control parameters of the 3DConnextion SpaceNavigator. A subsequent usability test consisting of a focus group and 20 individual tested participants brought the result that it is required to have an controller which allows anindependent control of different parameters (push/pull, rotate, …) simultaneously. The tested controller didn't meet this requirement.

Next steps in the development of the interface will be 1.) to evaluate controller alternatives that meet the requirements denoted before, 2.) to add the possibility for navigation within different parts of the space independently, 3.) to introduce other pitch spaces to play other and more complex chords and scales and 4.) to develop an advanced visualization.

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