New Cognitive Theories of Harmony Applied to Direct Manipulation Tools for Novices

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NEW COGNITIVE THEORIES OF HARMONY
APPLIED TO DIRECT MANIPULATION TOOLS FOR

NOVICES

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Abstract

Two recent cognitive theories of harmony can be
exploited to design powerful direct manipulation tools to
help novices sketch, analyse and experiment with
theories are the focus of much current investigation by
cognitive psychologists of music but they also offer
considerable potential, so far virtually unexploited, in music
education and musicians-machine interface design.

Longuet-Higgins and Balzano start from quite different
bases, (one from the overtone series and the other from
mathematical graph theory) but the two theories lead to
closely related two-dimensional representations of
harmonic structures and relationships. The paper discusses
the design of direct manipulation tools based on a version
of Longuet-Higgins' theory to allow novices to modify,
sketch and analyse harmonic sequences simply and closely
determined by moving two-dimensional patterns representing
notes, chords and key areas on a computer screen linked to
a synthesizer. Such interfaces should enable novices to
experiment intelligently with harmony in ways that
might normally be barred to them because of lack of
theoretical knowledge or instrumental skill.

1 Introduction

This research is part of a wider project to find ways of
using artificial intelligence to encourage and facilitate
beginners to compose music for enjoyment. The wider
project is aimed at novices who may not have a formal
musical education and at users outside as well as inside
the formal education system. (For this reason we will use
popular music and jazz illustrations, although the tools
work with any harmony in any genre.) The research
explores two recent cognitive theories of harmony
(Longuet-Higgins, 1982) and (Balzano, 1980) which give
ris to principled and elegant representations for basic
harmonic relationships and harmonic movement. Because
of space limitations we will concentrate exclusively on
interfaces based on a modified version of Longuet-
Higgins' theory although closely related interfaces can be
designed using adaptations of Balzano's theory.

2 Longuet-Higgins theory

Longuet-Higgins' theory of the perception of harmony
involves the investigation of an array of notes arranged in
ascending perfect fifths on one axis and major thirds on
the other axis1 (Fig. 1). (Readers not interested in the
reasons for this could skip the rest of this section.)

Longuet-Higgins' (1982) theory asserts that the set of
intervals that occur in Western tonal music are those
between notes whose frequencies are in a ratio expressible
as the product of the three prime factors 2, 3, and 5 and no
others (Theorem 72). Given this premise, it follows that
the set of three intervals consisting of the octave, the
perfect fifth and the major third is the only non-redundant
co-ordinate space for all intervals in musical use. We can
represent this graphically by laying out notes in a three
dimensional grid with notes ascending in octaves, perfect
thirds and major fifths along the three axes. The three
octaves demarcate the space and practical convenience for
focusing on the other two dimensions (Fig 1).

The theory is of great interest to cognitive psychologists
of music (Shoboda 83), (Howell, Cross and West, 85).

1 In Longuet-Higgins' presentations of the theory, and
in all discussions of it in the psychological literature, the
convention is that ascending perfect fifths appear on the
x-axis and the ascending major thirds on the y-axis. In
my discussions of educational applications I reverse this
convention. The reversal originally happened accidentally, but
I now maintain it in educational contexts on three
grounds: firstly it allows students to switch more easily
between the Balzano representation & the 12-note version of
the Longuet-Higgins representation (which could both be
available on a single interface for different tasks) - the
x-axes coincide and the y-axes are related as if by a sheer
operation. Secondly it makes the dominant &
subdominant area coincide with Schoenberg's (54)
dominant & subdominant regions (though of course the
x-axes and the overall meaning of the respective diagrams
differ). Thirdly the V-I moveiments that dominate Western
tonal harmony at so many different levels become aligned
with gravity in a metaphor useful to novices. To any
readers who find this convention confusing, I apologize.

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attempting to explain aspects of human musical intelligence, but we will focus here on using the theory for developing new educational tools.

\[ \text{Cub, A, C, E, G, Bb} \]

Perfect 5ths

\[ \text{D, F, A, C, E, G} \]

key window for key of C Major

\[ \text{E, G, B, D, F#, A} \]

Major thirds

However, for the purposes of educating novices in the elementary facts of tonal harmony we map Longuet-Higgins space onto the twelve note vocabulary of a fixed-rooting instrument resulting in what we might call "12-tone two-dimensional Longuet-Higgins harmony space" or "2D harmony space for short. Consequently we lose the double sharps & double flats of fig 1, and the space now repeats exactly in all directions (fig 2). Notes with the same name really are the same note in this space. In fact a little thought will show that the space is, in fact a torus, which we have unfolded and repeated like a wallpaper pattern.\(^2\) One result of this is that instead of a single key window we have a repeating key window (fig 2).

\[ \text{C, E, G, B, D, F} \]

5ths

\[ \text{D, F, A, C, E, G} \]

perfect 5ths using 12-note pitch set

\[ \text{E, G, B, D, F#, A} \]

major thirds using 12-note pitch set

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**Fig 1**

**Fig 2**

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### 3.1 Representing the 'Statics' of Harmony

#### 3.1.1 Representing key areas and modulation

In diagrams such as fig 1 all of the notes of the diatonic scale are "chumped" into a compact region. For example, all of the notes of C major, and no other notes are contained in the box or window in fig 1. If we imagine the box or window as being free to slide around over the fixed grid of notes and delimit the set the notes is lies over at any one time we will see that moving the window vertically upwards or downwards, for example, corresponds to modulation to the dominant and subdominant keys respectively. Other keys can be found by sliding the window in other directions. Despite the repetition of note names, it is important to note that notes with the same name are different positions are not the same note, but notes with the same name in different keys (Staandard 72) calls these 'homonyms'). This is an extension motivated by Longuet-Higgins theory, of the standard notational distinction that C, double sharp, for example, is not the same note as D. (Steedman calls such pairs "homophones")

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\(^2\)We have used arbitrary spellings in these diagrams (e.g., F# instead of Gb etc.), but an environment could equally easily use natural semitone numbers or any preferred convention. The convention could even be dynamically affected by changes in the position of the key window.
Notice also that we have a clear spatial metaphor for the centrality of the tonic—the tonic triad is literally the central one of the three major triads of any major key. We can make similar observations for the minor triads. Minor triads correspond to minor-L-shapes. Like major triads, they are maximally compact three-element objects in the space. The three secondary triads generate the natural minor (and major) scale (We could deal with harmonic and melodic minor scales by extending the key window, but we do not pursue this here). Also, the space gives a clear visual metaphor for the centrality of the relative minor triad among the secondary triads.\(^3\) Completing the full set of scale tone triads for the major scale, the diminished triad is a sloping straight line. Some musical dialects, especially in areas of popular music consistently use seventh or ninth chords in place of triads. These chords similarly have memorable and consistent shapes in the space. See Fig 4 for the representation of scale tone seventh.

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\text{Major triads in C major: L, IV and V}
\text{Minor triads in C major: II, III, and VI}
\text{Diminished chord VII}
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Fig 3 Triads in C major

3.2.3 Chords and keys in a direct manipulation environment.

Let us pause to imagine a direct manipulation environment based on the theory as described so far. We have a grid of notes on the screen and two mice (or one mouse and a set of arrow keys). One mouse controls the location of a moving dot that sounds any notes it passes over, provided the mouse button is down at the time. Equally easily we can set the mouse to control the location of the root of a diad, triad, seventh or ninth chord. As we move the root around, the quality of the chord will change appropriately in the position of the root in the scale. There will be a clear visual metaphor for this constraint, because the shape of the chord will appear to change to fit the physical constraint of the key window. The other mouse can be assigned to move the key window. Moving this mouse corresponds to changing key. If, for example we modulate by moving the window while holding a chord root constant, the chord quality may change. Once again there will be a clear visual metaphor for what is happening since the shape of the chord will appear to be "squeezed" to fit the new position of the key window. Note that the proposed environment is linked to a synthesizer and that everything we have described can be heard.

3.2.2 Representing the 'Dynamics' of harmony

3.2.2.1 Simple two and three chord movements.

So far we have used 3D harmony space to look at the representation of key areas and chords. Let us now move on to look at harmonic succession and progression. A fundamental I V I progression can be seen visually as one that begins on the central major triad of the key, and then moves to a maximally close neighbor before returning home (Fig 3). Similarly, progressions involving I, IV and V can be seen as oscillating either side of the usual centre by the smallest possible step and then returning home.

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\text{Scale tone Major sevenths in C major: I and IV}
\text{Scale tone Minor sevenths in C major: II, III, and VI}
\text{Dominant seventh chord V}
\text{Diminished chord VII}
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Fig 4 Scale tone 7ths in C major

3.2.2.2 Manipulating and representing cycles of fifths

Moving onto wider chord vocabulary, progressions like II V I, VI V I, III VI II V I etc correspond to straight
lines vertically downward in 2D harmony space with the
tonal centre as their target (Fig. 5). We refer to straight
line motions in 2D harmony space to tonal goals as
harmonic trajectories. 4 In particular, if we begin a trajectory vertically downwards in a cycle of fifths from
I or IV, it turns out there are two classes of trajectory that
we could make. In the case (tonal cycle of fifths) we use
only notes in the key - physically this is a straight line
that bends or jumps where necessary 5 to remain in the
key window (Fig 5b and 5c excluding shaded points). In
the other case (real cycle of fifths) the root moves
unremittingly in a straight line down the perfect fifth
axis, necessarily cutting across areas not in the key
window 6 (Fig 5c shaded points). In the proposed exact
manipulations environment we could sketch a 2D cycle
of fifths by selecting an option that constrained the root
to remain within the key window together with a second
option causing the chord quality to be dynamically
adjusted according to the position of the root relative to
the window. Having done this, if we made a vertical
straight line gesture with the mouse to play the cycle of
fifths, the size of the root span could be seen and heard
adjusting at one point to stay in key as the root came to
the bottom edge of the key window (fig 5b or c), and the
chord quality could be seen and heard flexing to fit within
the key window (fig 3 and 4). This would work even if
there were modulations (movements of the key window)
and chord sequence. To play a real cycle of fifths, we
would simply switch off the options that constrained root
position and chord quality. 7 The harmony of wide areas
of Western tonal music is dominated by harmonic
trajectories of chords and keys moving down the dominant
axis. (See (Prest 84) for a version of this thesis in more
conventional language focussing on Bach, Schubert and
Mozart.) If we reverse the direction of the arrow and
consider chord sequences moving vertically upwards, we

4 In deliberate imitation of Leviton's (1983) use of the
term trajectory to refer to the distinct but related
phenomenon of melodic trajectory.
5 e.g if we are in the key of C, the root moves in a
diminished fifth from F to B.
6 For chords outside the key window, simple harmonic
considerations cannot determine the default chord quality.
Different pieces and different dialects use different
solutions depending on the musical purpose involved.
7 Other selectable options could include manually
customizing the default chord quality at any time, holding
it constant or putting it under program control.

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4 Analyzing real music in 2D harmony space
So far we have shown that a 2D slice through Longuet-
Higgins space can provide economical descriptions of
aspects of the statics and dynamics of harmony. Let us
now turn to the harmonic successions of a real piece of
music. Fig 8 gives the chord sequence of the jazz

8 This kind of analysis is different from and simpler
than, for example Longuet-Higgins' analysis of Schubert.

Fig 5 Cycles of fifths
standard: “All the things you are.” Beware of limitations of space we will only consider the first 8 bars, but fig 8 gives a harmonic space trace of the whole chord sequence, and the analysis could easily be continued. For clarity, only the root of each chord is indicated, and chord alteration is indicated by superscript.

4.1 Example analysis

From an analytic point of view, the song breaks into a small number of recognizable harmonic plans (we only know of two to deal with the first one). In the first eight bars, the sequence begins on a VI chord and makes a dominant-toned major II trajectory towards the tonic E7 (with what we know at this stage the goal being presumably the major I, though it could be the relative minor VI). But the sequence plunges on past I at the fourth bar onto IV at the fifth bar. The song at this point is in danger of breaking a standard convention for the diatonic. In jazz “standards” show in a convention that we normally expect to reach a tonic goal when we hit the major (or minor) of the tonic at the end of each line (normally eight bars). In this case it seems we are shooting for a tonic goal but overshoot it. The solution used becomes in effect the harmonic motif of the whole piece - we move the goalpost. This is achieved by a timely transient allowing the progression to reach the tonic goal in the nick of time. In the direct manipulation environment, the moving goalpost metaphor is demonstrated literally. The environment would physically show (fig 8) the ‘goalpost’ in the shape of the key window being moved sideways so that the tonic cycle of fifths drops into the goal or tonic octave as the audible metric boundary. The broad outlines of this analysis should be immediately comprehensible to a novice with access to the direct manipulation tools being discussed.

It is important to note that a visual formalism is not being proposed as a substitute for listening. It is being suggested that an animated implementation of the formalism linked to a sounding instrument may allow novices without instrumental skills to gain experience (62) and Freedman’s analysis of Bach (72) using the full space.

9Pratt (84): phrase.

It is common in this dialect where all chords are routinely played as sevenths to emphasize arrival at the tonic (with relentless chord quality major seventh) by repeating it as a more stable major minor.

of controlling and analyzing such sequences without knowledge of classical theory and terminology. But such an environment might be also be a good place to learn music theory if the novice desired.

5 Educational use

The direct manipulation design considerations so far discussed could be the basis of a family of environments for analysis, modification, playback and sketching of harmonic sequences as well as an aid to learning theory. As a sketching device, multiple mice could control, for example, independent melody, bass and accompaniment voices. The system could permit dynamic association of varied rhythmic figures, Alberti patterns and arpeggiation with given voices. Analysis could be carried out at low or high level. Tonal centres and roots could have been already identified at the interface used to help illuminate the higher level harmonic structure of a piece as in fig 8. Alternatively the student could use a version of the interface as an aid to help identify tonal centres, roots, modulations and perform the graphic equivalent of traditional arithmonic analysis. Modification involves taking an existing piece and manually altering its annotated graphic trace to discover where small changes make big changes to the musical sense and vice versa. 2D harmonic space tools could be used as valuable aids for studying practically any theoretical aspect of tonal harmony (e.g. the relationship between modal harmony and tonal harmony, aspects of the evolution of major/minor tonal centres etc.). The environment could automatically convert 2D harmony space displays into Common Music Notation and vice versa to assist this.

Fig 6 and 7: scalar and chordic progressions

The ideas described so far give rise to a number of issues
"All the things you are" chord sequence in 12-tone 2D Harmony space

(Chord sequence expounded from Molegus (1954), "All the things you are" and for further elaboration see Appendix B: Harmony and Reduction, pp. 236 and 246 in T: H.)

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which we can only outline here. These issues are all addressed in the research in progress of which this work forms part. The first problem is that to understand a chord sequence you usually need to know about its melodic context (as in the analysis above). A graphic notation has been developed to help address this problem.

The second problem is that in a practical system, some means of controlling and displaying inversions and pitch register is needed. Some partial solutions have been devised. Thirdly, we have so far emphasized vertical aspects (in the traditional sense) at the expense of linear aspects of harmony. To a large extent this is an inherent limitation of 2D harmony space, but contrasting display strategies have been devised with partial success in special cases to selectively emphasize linear or chordal aspects of harmonic movement.

There is a potentially far more serious problem that fortunately has a satisfactory solution. The problem is that in a practical interface whose notes are not artificially constrained to fall within one octave, the diagonal (chromatic/harmonic) axis will wind up as a major seventh axis. Fortunately this problem can be addressed by using Balzano’s representation of place of Longuet-Higgins’ but bringing across the idea of a movable key window. Balzano’s theory leads to a note array similar to the 12-note version of Longuet-Higgins but with axes of major third and major third. One diagonal axis turns out to be the cycle of fifths and the other diagonal axis a true chromatic axis. It turns out that the Balzano representation works satisfactorily both theoretically and practically for the kind of interfaces we are discussing. Unfortunately space limitations do not permit us to discuss this class of interfaces and the interesting issues that emerge comparing the suitability of the two kinds of interface for different tasks.

7 New developments

2D harmony space is perhaps best viewed not as one tool but a family of tools. Other members of the family investigated include a rubber-band “MacDraw-like” version of the environment and a “turtle Logo-like” programming language to control “harmonic turtles” in 2D harmony space. From an Artificial Intelligence and Education point of view, the 2D harmony space family of environments can be viewed as examples of what are known as discovery learning environments or micro-worlds. In order to tackle the problem common to such environments (Ellen-Cook, 84) of providing guidance tailored to individuals, 2D harmony space is being linked to an intelligent knowledge-based tutor for music composition under design as discussed in Holland (87). The linked system will then become a guided discovery learning environment for aspects of music composition in a variety of styles.

8 Two further perspectives

One useful perspective can be provided by an analysis between Turtle Logo which embodies the mathematically pervasive 20th century concept of the function and harmony space. A 2D harmony interface would embody a similarly powerful and appropriate representation for relationships in tonal harmony.

A second perspective is the Xenos Star/Macintosh human computer interface analogy. Design aims for the human machine interfaces of these machines included consistency, simplicity, reduction of short-term memory load and exploitation of existing knowledge. A 2D harmony space tool goes some way towards meeting these aims: for a harmony sketcher, since harmonic constraints and the relationships between keys are visibly and physically externalized consistently to a higher degree than in the case of stringed instruments, keyboard instruments and conventional music notation.

9 Implementation

An early partial prototype of harmony space was implemented in Common Lisp using the interface design tool Dialog on an Apollo Domain workstation controlling a Yamaha TX816 synthesizer via a Hinton MIDI RS232 to MIDI converter in Jan 1987.

Conclusions

Longuet-Higgins’ (1962) and Balzano’s (1980) theories are the focus of much current investigation by cognitive psychologists of music, but they also offer considerable potential in music education and musician-machine interface design. We have discussed how a family of direct manipulation tools based on the theories can be designed to allow novices to modify, sketch and analyse harmonic sequences simply and clearly by moving two-dimensional patterns representing notes, chords and key areas on a computer screen linked to a synthesizer. Such interfaces should enable novices to sketch, analyse and
experiment productively with harmony in ways that might normally be barred to them because of lack of theoretical knowledge or instrumental skill. The report from which this paper stems (Holland 86) appears to be the first discussion of educational use of Longuet-Higgins' theory, and its use for controlling as well as representing music.

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References


Appendix: Chord symbol conventions
Roman numerals representing scale tone triads or sevenths I II III IV V etc. are written in capitals, irrespective of major or minor quality. Roman numerals represent chords of the quality normally associated with the degree of diatonic (or modality) prevailing. We call this quality the "default" quality. In the jazz example, Roman numerals indicate scale-tone sevenths rather than triads. The following post-fix symbols are used to annotate Roman chord symbols to override the "default quality as follows: x - dominant, a - diminished, # - half diminished, m - minor, M - major. The following post-fix convention is used to alter indicated degrees of the scale: "#5" means default chord quality but with sharpened 3rd, "7#" means default chord quality but with sharpened 7th etc. The following post-fix convention is used to add notes to chords e.g. "+6" means default chord quality with added scale-tone sixth. The prefixes # and b move all notes of the otherwise indicated chord's semitones up or down.