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 musicians sketch, analyze and experiment with
harmony. 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, so far virtually unexploited, in music
education and music-as-machine interface design.
Longuet-Higgins and Balzano start from quite different
bases, (one from the overtone series and the other from
mathematical group 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 analyze 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
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 bass harmony in any genre.) The research
explores two recent cognitive theories of harmony
(Longuet-Higgins, 1962) and (Balzano, 1980) which give
rise to principled and elegant representations for basic
harmonic relationships and harmonic movement. Because
of space limitations we will concentrate exclusively on
interference 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 axes 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' (62) 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 (Moore 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
non-4t dimensions discussed in most discussions on
grounds of octave equivalence and of practical convenience
for focusing on the other two dimensions1 (Fig. 1).
The theory is of great interest to cognitive psychologists
of music (Shuboda 87), (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. I
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 which more easily
between the Balzano representation & the 12-tone 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 by a shear
operation. Secondly it makes the dominant &
subdominant areas 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 movement that dominates Western
tonal harmony at all many different levels becomes aligned
with gravity in a metaphor useful to novices. To any
readers who find this convention confusing, I apologize.
attempts to explain aspects of human musical intelligence, but we will focus here on using the theory for developing new educational tools.

Fig 1

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 "chomped" 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 treated with the same name in different keys (Standen 72); this calls these "homonyms"). This is an extension motivated by Longuet-Higgins' theory, of the standard tonal distinction that C major and C sharp, for example, is not the same note as D. (Swedman calls such pairs "homophones")

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-instrument instrument resulting in what we might call '12-note two-dimensional Longuet-Higgins harmony space'. 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. One result of this is that instead of a single key window we have a repeating key window (fig. 2).

Fig 2

2.1.2 Representing chords and tonal centres

Let us now turn to look at the representation of triads and tonal centres. In 2D harmony space, major triads correspond to L-shapes (fig 3). A triad consists of three maximally close distinct notes in the space. The dominant and subdominant triads are maximally close to the tonic triad. We can instantly see from the diagram that the three primary triads contain all the notes in the diatonic scale.

We have used arbitrary spellings in these diagrams (e.g., F sharp instead of Gb, etc.), but an environment could equally easily use neutral semitone numbers or any preferred convention. The convention could even be dynamically affected by changes in the position of the key window.

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Notes also that we have a clear spatial metaphor for the centrality of the tonic - the tonic triad is literally the center of the three major triads of any major key. We can make similar observations for the minor triads. Minor triads correspond to minor L-shapeds. 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.

![Figure 3: Triads in C major](image)

**3.2 Representing the 'Dynamics' of Harmony**

3.2.1 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.

![Figure 4: Scale tone 7ths in C major](image)

3.2.2 Manipulating and representing Cycles of Fifths

Moving onto wider chord vocabulary, progressions like II, V, VI, VII, V, VI, VII 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. 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 one 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
uninterruptedly in a straight line down the perfect fifth
axis, necessarily cutting across areas not in the key
window (Fig 5a shaded points). In the proposed direct
manipulation environment we could sketch a tonal 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 step would 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)
ad chord sequence. To play a real cycle of fifths, we
would simply switch off the options that constrained root
position and chord quality. The harmony of wide areas
of Western tonal music is dominated by harmonic
trajectories of chords and keys moving down the dominant
axis. (See (Pest 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
have what might be called extended played sequences and
cadences. This kind of chord sequence is occasionally used
in popular diatonic music, for example "Hey Joe" (popular
an. Jimi Hendrix) as discussed by Steffen (83).

2.3 Manipulating chromatic and scalar sequences

Scalar sequences (i.e. movement up and down the
diatonic scale) can be represented as diagonal trajectories
constrained to remain within the key windows (fig 6). So
for example, the chord sequences I II III IV, I IV III II,
etc. can be represented as diagonal trajectories or diagonal
collisions. Scalar root movement occurs frequently in
tonal music in short sequences and is often used in longer
sequences in modal music. If the constraint is removed,
that the root must stay within the key window, scalar
sequences become chromatic sequence (fig 7). Chromatic
chord succession are widely used in some dialects of modal
music, particularly in jazz dialects. (Footnote 6 applies here too).

4 In deliberate imitation of Levitt's (1985) 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.

6For 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.

7Other selection options could include manually overwriting
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 12-note adaptation of Longuet-
Higgins space can provide economical descriptions of
aspects of the music and dynamics of harmony. Let us now
look at the harmonic successions of a real piece of
music. Fig 8 gives the chord sequence of the jazz

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

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standard. "All the things you are," the rest of limitations of space we will only consider the first 8 bars, but fig 8 gives a harmony 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 space to deal with the first one). In the first eight bars, the sequence begins on the VI chord and makes a dominant-powered trajectory towards the tonal center (from 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, "standard" tune is a convention that we normally expect to reach a tonal goal when we hit the major minor boundary at the end of each line (normally eight bars). It is as though we were shooting for a tonal goal but overshoot it. The solution used becomes in effect the harmonic motif of the whole piece - we save the goalpost. This is achieved by a timely transient resolved allowing the progression to reach the tonal 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 tonal cycle of fifths drops into the goal or tonal center at 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 (63) and Freedman's analysis of Bach (72) using the full space.

The ideas described so far give rise to a number of issues of controlling and analyzing such sequences without knowledge of standard 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 pattern and arpeggiation with given voices. Analysis could be carried out at low or high level. Tonal centres and roots could have been already identified and the interface used to help illuminate the higher lever 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 centre, roots, modulations and perform the graphic equivalent of traditional harmonic 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 harmony 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: scale and chromatic 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

- Bar 1-5: Starting key I
- Bar 6-8: Modulates up a major third in bar 6
  (Arrow shows direction of Key window shift)
- Bar 9-13: Modulates up a minor third in bar 9
- Bar 14-15: Modulates up a major third in bar 14
- Bar 16-20:
- Bar 21-24: Modulates down a minor third in bar 21
- Bar 26-28: Modulates up a major 2nd in bar 24

(Chord sequence excerpted from Mobiles (1959); "All the things you are" excerpt from "Embraceable You"
In Coda: Permutaions of 16 notes for 2 voices
by Robert Moog and Y. H.
Harmon Co.

See appendix for explanation of chord symbol notation.

Fig 8

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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 to understand a chord sequence you usually need to know about its material context (as in the analysis above). A graphic notation has been devised 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 justic) axis will act as a major seventh axis. Fortunately this problem can be addressed by using Balzano's representation in 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 minor 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 interface 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 environment for different tasks.

New developments

2D harmony space is perhaps best viewed not as on tool but a family of tools. Other members of the family investigated include a rubber-hand '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 microworlds. In order to tackle the problem common to such environments (Elson-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 idioms.

Two further perspectives.

One useful perspective can be provided by an analogy between Turtle Logo which embodies the mathematically pervasive 20th century concepts 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 Xenon 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: aims for a harmony sketcher, since harmonic constraints and the relationships between keys are visually and physically externalized consistently to a higher degree than in the case of stringed instruments, keyboard instruments and common music notation.

9 Implementation

An early partial prototype of harmony space was implemented in Common Lisp using the interface design tool DialogC on an Apollo Domain workstation controlling a Yamaha TX816 synthesizer via a Hinton MIDIC 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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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 triads
of the quality normally associated with the degree of
harmony (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:
-
- dominant, O - diminished, # - half diminished, m -
inversion, 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. The
prefixes # and b move all notes of the otherwise indicated
cord's semitones up or down.