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
harmony. Longuet-Higgins' (1982) 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
unexplored, in music education and music-computer
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 analyse harmonic sequences simply and easily
by moving two-dimensional patterns representing
notes, chords and key areas on a computer screen linked
to a sound synthesis. 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
rise 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 axis (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 (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 geometrically by laying out notes on a three
dimensional grid with notes ascending in octaves, perfect
thirds and major fifths along the three axes. The notes
hence defined in musical applications include consonances
and dissonances associated with such pitch intervals.
(2)

In Longuet-Higgins' presentations of the theory, and
in all discussions of it in the psychological literature,
the consonance 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
notation. 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 sheave
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 movements 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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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 delineate the set of notes that overlaps 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 (Staude's ref. [72] calls these 'homonymes'). 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. (See section on pitch '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-root instrument resulting in what we might call '12-note 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. 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 chordal and tonal centres

Let us now turn to look at the representation of chords 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# instead of Gb etc.), but an environment could equally use neutral seventh 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-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.

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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**Fig 3 Triads in C major**

<table>
<thead>
<tr>
<th>Major triads in C major</th>
<th>Minor triads in C Major II, III and VI</th>
<th>Diminished chord VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>I, IV and V</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>E</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>

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**Fig 4 Scale tone 7ths in C major**

<table>
<thead>
<tr>
<th>Scale tone Major sevenths in C Major I and IV</th>
<th>Scale tone Minor sevenths in C Major II,III and VI</th>
<th>Dominant seventh chord V</th>
<th>Diminished chord VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>E</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>B</td>
<td>G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**3.2 Representing the 'Dynamics' of harmony**

**3.2.1 Simple two and three chord movements**

So far we have used 2D 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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**3.3.2 Manipulating and representing Cycles of Fifths**

Moving onto wider chord vocabulary, progressions like II V I, VI II V I, III VI II V I etc. correspond to straight...
lines vertically downward in 2D harmonic space with the
tonal centre as their target (Fig. 5). We refer to straight
line motions in 2D harmonic space to tonal goals as
harmonic trajectories. 6 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
uninterrupted in a straight line down the perfect fifth
axis, steeply cutting across areas not in the key
window 6 (Fig 5c 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 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)
mid-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 focusing 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 dialects as in, for example, "Hey Joe" (popular
arr. Jimi Hendrix) as discussed by Steedman (83).

3.2.3 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, for chord sequences I I I I I I I, I V V V V
etc. can be represented as diagonal trajectories or
diagonal oscillations. 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 sequences (fig 7). Chromatic
chord succession are widely used in some dialects of total
music, particularly in jazz dialects. (Footnote 6 applies here too.)

4 Analyzing real music in 2D harmonic space
So far we have shown that a 2-note adaption of 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. 8 Fig 8 gives the chord sequence of the jazz
4 This kind of analysis is different from and simpler than
for example Longuet-Higgins’ analysis of Schubert.
standard: "All the things you are". By now of limitations
of space we will only consider the Text 8 bars, but fig 8
gives a harmony space trace of the whole chord sequence,
and the analysis could equally be continued. For clarity,
only the root of each chord is indicated, and chord
alteration is indicated by notation.

4.1 Example analysis
From an analytic point of view, the song breaks into a
small number of recognizable harmonic plans (we only
take space to deal with the first one). In the first
four bars, the sequence begins on a VI chord and makes a
dominant-powered trajectory towards the tonal centre
(from what we know at this stage the goal being
presumably the major I, though it could be the relative
minor V6). But the sequence ploughs 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
diadect, in jazz "standards" there is a convention that we
normally expect to reach a tonal goal when we hit the
major metric boundary of the end of each line (normally
eight bars). It is as though we were shooting for a tonal
goal but overshooting. The solution used becomes in effect
the harmonic motif of the whole piece - we arrive
at the goalpost. This is achieved by a timely transient
resolution allowing the progression to reach the final
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 centre 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 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.

Pratt (84) phrase.

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

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 applications
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
various 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 and 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 harmonic analysis. Modification involves
taking an existing piece and manually altering 'un-
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.

Figs 6 and 7: scalar 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

hary 1-5
Starting key I

V

hary 9-13
Modulates up a minor third in bar 9

VII

hary 16-15
Modulates up major third in bar 14

hary 16-20

hary 21-24
Modulates down a minor third in bar 21

hary 24-28
Modulates up a major third in bar 24

hary 28-36

(Chord sequence reproduced from Molina (1989a), "All the things you are," for Quinto OctavoHarmony, page 62, with permission. Elmer Co.)

(AB) VI / II / V / I / IV / V / II / V / I
(BB) VI / V / I / IV / II / V / I / IV / II
(A) V / I / IV / II / V / I / IV / II
(B) VI / I / IV / II / V / I / IV / II
(C) V / I / IV / II / V / I / IV / II

See appendix for explanation of chord symbol notation.

Fig 8
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
choral sequence you usually need to know about its
metrical 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 emphasised 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 emphasise linear or chosen
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 justicat) axis will avoid 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 environment for different tasks.

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 a 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
(Ellson-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.

8 Two further perspectives.
One useful perspective can be provided by an analogy
between Turtle Logo which embodies the mathematically
persuasive 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 Xenon Star/Macintosh human
computer interface analogy. Design aims for the human
machine interfaces of these machines included
compositional consistency, simplicity, reduction of short-term memory
load and exploitation of existing knowledge. A 2D
harmony space tool goes some way towards meeting
these design aims for a harmony sketcher, since harmonic
consistency and the relationships between elements are visually
and physically externalised 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 Dialog© on an Apollo Domain workstation
controlling a Yamaha TX816 synthesizer via a Minot
MDIC RS232 to MIDI converter in Jan 1987.

Conclusion
Longuet-Higgins’ (1962) and Balzano’s (1980) theories
able 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 synthesiser. 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.

Acknowledgements
Thanks to Mark Eason-Cook for constant support, encouragement and guidance. This paper would not have existed without Mark Steedman's suggestion that Longuet-Higgins' theory was a good area to explore for educational applications. Thanks to Tim O'Shea for making it possible. Thanks to Mark Steedman, John Slobo, Trevor Bray and Richard Middleton for comments on an earlier draft. Thanks to Christopher Longuet-Higgins, Ed Little and Mike Baker for valuable discussions. Thanks to Mark Eason-Cook for help beyond the call of duty with specialized graphics, lab and interface programming. Thanks to Caroline, Simon & Peta for three things more important than 3D harmony space. Not all criticisms have yet been adopted, so responsibility for all errors lies definitely with the author. The support of this work by the ESRC is gratefully acknowledged.

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 triads of the quality normally associated with the degree of tonality (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, o - diminished, a - half diminished, m - minor, M - major. The following post-fix convention is used to alter indicated degrees of the scale: "m" means default chord quality but with sharpened 3rd, "7m" 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 6th. The prefixes # and b move all notes of the otherwise indicated chord a semitone up or down.