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' (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 unexplored, in music
education and music/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 analyse harmonic sequences simply and clearly.
Two-dimensional patterns representing notes, chords and
key areas on a computer screen linked to a synthesiser. 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 music in any genre.) The research exploits
two recent cognitive theories of harmony
(Longuet-Higgins, 1942) 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 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 (Theorem 7). 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 occurring in octaves, perfect
thirds and major fifths along the three axes. The n-cube
dimensions discussed in most discussions on grounds of
octave equivalence and of 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)
attempts to explain aspects of human musical intelligence, but we will focus here on using the theory for developing new educational tools.

However, for the purposes of educating novices in the elementary facts of tonal harmony we map Longuet-Higgins space onto the twelve notes vocabulary of a fixed-root 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. One result of this is that instead of a single key window we have a repeating key window (fig 2).

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 dilate 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 ones with the same name in different keys (Steadman (72) calls these 'homonyms'). This is an extension, motivated by Longuet-Higgins theory, of the standard tonal distinction that C double sharp, for example, is not the same name as D. (Seedman calls such pairs "homophones".)

Fig 1

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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 minimally 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 popular music consistently use seventh or ninth chords in place of triads. These chords similarly have measurable and consistent shapes in the space. See Fig. 4 for the representation of scale tone vectors.

3.2 Representing the 'Dynamics' of harmony

3.2.1 Single two and three chord movements

So far we have used 3D harmonic 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 neighbour before returning home (Fig. 5). 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.
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 to remain in the key window (Fig 5b and 5c excluding shaded points). In the other case (real cycle of fifths) the root moves unrestrictingly in a straight line down the perfect fifth axis, necessarily cutting across areas not in the key window (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 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 5 and 6). 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. The harmony of wide areas of Western tonal music is dominated by harmonic trajectories of chords and keys moving down the dominant axis. We refer to this approach as the arrow and consider chord sequences moving vertically upwards.

4 In deliberative 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.

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 selected options could include manually editing the default chord quality at any time, holding it constant or putting it under program control.

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 artist Hendrix) as discussed by Steinman (83).

3.3.1 Manipulating chromatic and scalar sequences

Scallic 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 I I VII etc. can be represented as diagonal trajectories or diatonic oscillations. Scale 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, scallic sequences become chromatic sequence (fig 7). Chromatic chord successions are widely used in some dialects of modal music, particularly in jazz dialects. (Footnote 6 applies here too).

![Fig 5 Cycles of fifths](image)

4 Analyzing real music in 2D harmony space

So far we have shown that a 2-D ontology 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. Figure 8 gives the chord sequence of the jazz

This kind of analysis is different from and simpler than, for example Longuet-Higgins’ analysis of Schubert
standard. "All the things you see". The state 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 inversion.

4.1 Example analysis

From an analytic point of view, the song breaks into a small number of recognisable harmonic plans (we only know space to deal with the first one). In the first eight bars, the sequence begins on a VI chord and makes a dominant-tonic trajectory towards the tonic centre (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 dialect. In jazz "standard" tune is a convention that we normally expect to reach a tonic goal when we hit the major metric boundary at the end of each line (naturally eight bars). It is as though we were shooting for a tonic goal but overshoot it. The solution used becomes in effect the harmonic motif of the whole piece - we arrive the goalpost. This is achieved by a timely transient accommodation 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 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 Sowden's analysis of Bach (72) using the full space.

9Pratt (84) phrase.

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

of controlling and analysing such sequences without knowledge of standard theory and terminology. But such an environment might be also 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 strappado 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 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.

![Image]

Figs 6 and 7: scalar and chromatic progressions

6 Problems and partial solutions

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 extrapolated from Melodies (1956). "All the things you are" and Itsôtel Theme (Theme for the Chamber Symphony) both used for this purpose. Huffman Co. 1987 ICMC Proceedings.
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 metrical 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 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 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 ascendant) axis will appear as a major seventh axis. Fortunately this problem can be addressed by using Balzano’s representation is place of Longuet-Higgins’ but bringing across the idea of a movable key window. Balzano’s theory (1977) offers a route similar to the 12-tone 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 see 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 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

8 Two further perspectives

One useful perspective can be provided by an analogy 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 Xerox 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 visually and physically externalised consistently to a higher degree than in the case of stringed instruments, keyboard instruments and common music notation.

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 DS222 to MIDI converter in Jan 1987.

Conclusions

Longuet-Higgins’ (1962) and Balzano’s (1989) theories 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 theory 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.

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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 triads of the quality normally associated with the degree of the 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, s = 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 6th. The prefixes # and b move all notes of the otherwise indicated chord's semitones up or down.

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