Computer-aided Composition from Melodic Contours and Tabular Constraints

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Abstract

The goal of this work is to develop a framework of intelligent computer-aided composition based on melodic contours and tabular constraints. Melodic contour is derived from whistling input as a MIDI controller. Tabular constraint is a flexible representation for describing, processing, and synthesizing musical structure of MIDI format music. Based on a given melodic contour, there are two main areas of computer-aided composition to be treated: melody variation and harmonization. We develop a musical plan representation called tabular constraints to allow the interactive experimentation for those two composition activities. A set of transformation operators is available for automatic composition. We have demonstrated that the integration of melody transcription and tabular constraints can allow a user to easily explore his potential in melody creation and harmonization.

1. Introduction

The research here is concerned with identifying ways to integrate both the melody transcription and computer-aided composition. This integration can allow an easy tune writer for convenient musical input (singing, humming or whistling) and interactive algorithm for musical composition. In our opinion, this integration becomes interesting in the sense that it underlies a composition based on transformations of musical structures, instead of focusing on low-level features, i.e., notes. Our approach for this integration is through melodic contour and tabular constraints.

Melodic contour refers to the shape of the melody, indicating whether the next note goes up, down, or stays at the same pitch. Dowling [1] and Handel [2] indicate that melodic contour is one of the most important methods that listeners use to determine similarities between melodies. Based on the significance of melody contours in human perception of music, Ghias[3] and McNab[4,5] separately developed systems for querying an audio database by humming the tune of a song. Chua[6] used pentatonic scales to explore some basic techniques of computer-aided composition (CAC). In [7], a system is developed to automatically derive a four voice score from a given melody. The expert system CHORAL [8] is also a system for harmonizing chorals in the style of J.S. Bach. Tsuruta[9] extended transcription into an automatic accompaniment generator for the sung melody.

From the literature mentioned above, there are few researches on integrating both melody transcription and algorithmic composition. Indeed, numerous efforts are required to extend a melody transcription system into a practical CAC system. To manipulate a given melodic contour and achieve a CAC system, we only concentrate on melodic variation and four-voice harmonization. Those are two important activities in music composition.

1.1 Composition as a Constraint Satisfaction Problem.

Given a few lines of melodic contour, the task of **melodic variation** and **four-voice harmonization** can be formulated into a constraint satisfaction problem, which consists of a finite set of ***variables*** $X=\{x_1,\dots,x_n\}$, a **function** which maps each variable x_i into a finite set D_i of possible values (its ***domain***), and a finite set of ***constraints*** restricting the combination of values that a set of variables may take simultaneously. To formulate melodic variation as a CSP, a sequence of transcribed melodic notes is taken as a finite set of ***variables*** $X=\{x_1,\dots,x_n\}$ that indicates the numeric pitch contour. A case of C major scale **(function)** that assigns each variable x_i into a finite set D_i of possible values (***domain***) may look as follows.

C major scale (function) : C D E F G A B
Numeric Contour (variables): 1 2 3 4 5 6 7

Tabular constraints {\,/} is to denote a falling melodic contour that follows a rising melodic contour. To formulate four-voice harmonization as a CSP, there are n * 4 variables where n is the number of chords in the sequence and 4 the number of tones (bass, tenor, alto and soprano) in each chord. For harmonic functions, tonic function or cadence forms can map the four voices into the possible domains. For tabular constraints, the harmonic labels are designed to express the progression of four-voice harmonization. The solution to the constraints-based composition is an assignment of a value from its domain to every variable, such that all constraints are satisfied at once.

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2. Melody Transcription

Figure 1 shows the processing flow of melody transcription that consists of 1) Signal conversion, 2) Musical primitive extraction (MIDI note number determination, Note segmentation, and tempo calculation). Signal conversion consists of A/D converter and FFT analysis. MIDI note number determination is to assign the fundamental pitches to MIDI note number. Note segmentation is to identify a note's duration. The tempo and meter is to determine bit per minute (BPM) and resolution for a quarter-note.

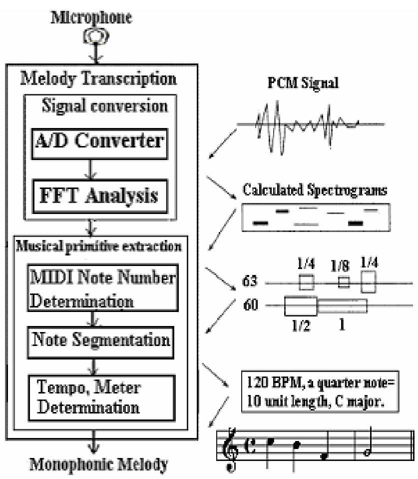


Figure 1. Process of a melody transcription system.

2.1. Template Matching for Melodic Contour

The research of melody transcription can be directed toward two directions; one is absolution transcription, the other is relative transcription. Given a melody input, the former tries to reproduce the perfect original wave in precise musical notation. The later tries to reproduce the similar melody by using the allowable musical symbols. There are two reasons to provide relative transcription. One is that every whistler's pitch range may vary. Using template matching, a numeric pitch contour for the chromatic scale is given as C(0), C#(1), D(2), D#(3), E(4), F(5), F#(6), G(7), G#(8), A(9), A#(10), B(11). Due to the whistler may whistle inexactly; so the rhythmic templates, which are sets of pre-defined duration, are used to approximate the transcribed note durations with the standard note duration as shown in Figure 2.

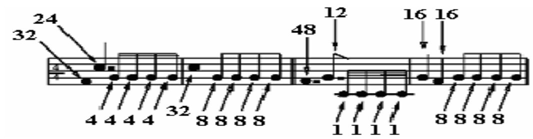


Figure 2. The transcribed note lengths in spectrogram are approximated to standard note durations.

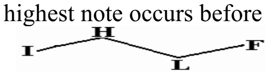
2.2. Representation of a Transcribed Melody

We use two kinds of variables to represent the features of a melodic contour. The numeric pitch contour in Figure 3 shows a two-dimensional matrix as: [0,0] [1,2] [2,3] [3,1], where the first number in each pair indicates the temporal order T (horizontal axis) and the second number represents the pitch P (vertical axis).

Figure 3. A numeric pitch contour.

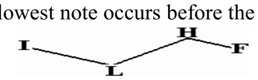
To simplify a numeric contour, shape variables are used. There are seven kinds of motif contours that can be represented by drawing a set of line segments through the four points.

(1). The highest note occurs before the lowest note.



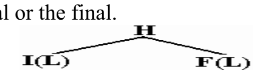
"**N**" is used to represent this motif shape.

(2). The lowest note occurs before the highest note.



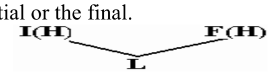
"**S**" is used to represent this motif shape.

(3). There are only three points; the lowest note is either at the initial or the final.



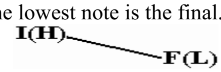
"**^**" is used to represent this motif shape.

(4). There are only three points; the highest note is either at the initial or the final.



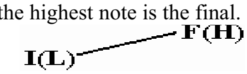
"**V**" is used to represent this motif shape.

(5). There are only two points; the highest is the initial, and the lowest note is the final.



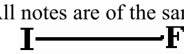
"\" is used to represent this motif shape.

(6). There are only two points; the lowest is the initial, and the highest note is the final.



"/" is used to represent this motif shape.

(7). All notes are of the same pitch.



"**-**" is used to represent this motif shape.

For motif contours (N,S,^,V), additional numbers are appended to those letters to designate the relative positions of the initial and the finial notes as follows: The initial that has the same pitch with the final is added with number "**1**". The initial that is higher than the final is added with number "**2**". The initial that is lower than the final is added with "**3**".

3. Melodic Variation

There are many techniques for melodic variations such as permutation, expansion, and transformation. Definitions, descriptions, and mathematical formulations of melodic variations by reflection are provided.

3.1. Motif Transformation of Tonal Reflection.

A tonal center must be set to serve as an axis of reflective symmetry. The forms of reflection can be designed as the following seven forms shown in Figure 4.

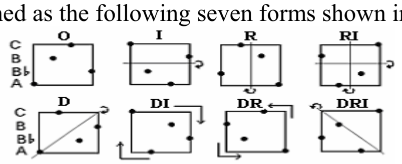
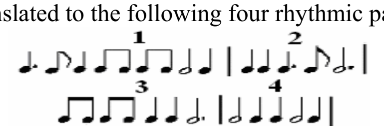


Figure 4. Seven forms of reflection.

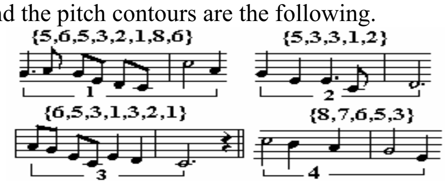
These may be defined mathematically as transformations of the O (original motif) as follows, where n = z-1, and z is the total number of pitch-value counts. The functions are **I(t,p) = O(t,n-p); R(t,p) = O(n-t,p); RI(t,p) = O(n-t,n-p); D(t,p) = O(p,t); DI(t,p) = O(p,n-t); DR(t,p) = O(n-p,t); DRI(t,p) = O(n-p, n-t).** All seven transformations, including I(inversion), R(retrograde), D(diagonal), RI, DI, DR(Diagonal retrograde), and DRI.

3.2. Melodic Form

One advantage of melodic form is that symmetry in melody can be arranged by the following tabular constraints: "/"⇔"\","N"⇔"S","^ "⇔"V","-"⇔"-". The other advantage is to assemble the small parts to a larger unit. Suppose a whistler creates four kinds of motifs. Motif 4 is {2,1,1,2,1}, etc. The derived rhythm contours are translated to the following four rhythmic patterns.



And the pitch contours are the following.



Then, a 16 bar music can be arranged by the motifs combination of 1-2, 1-3, 4-2, 1-3. The melodic form in Figure 5 shows that the length can be doubled by the methods of melodic variation.

Melody Line	Phrase Form	Phrase Range	Phrase I--F	Motif Contour Rhythm	Motif Contour Pitch	Section Form
1	a	P8	5-2	1/2	S3/V2	A
2	b	P8	5-1	1/3	S3/\	
3	c	P8	8-2	4/2	\/V2	B
4	b	P8	5-1	1/3	S3/\	
5	a'	P8	5-2	1/2	S3/V1	'A
6	b	P8	5-1	1/3	S3/\	
7	c	P8	8-2	4/2	\/V2	B'
8	b'	P8	5-1	1/3	S3/\	

Figure 5. An example of melodic form

The concrete music created by the melodic form is shown in Figure 6.

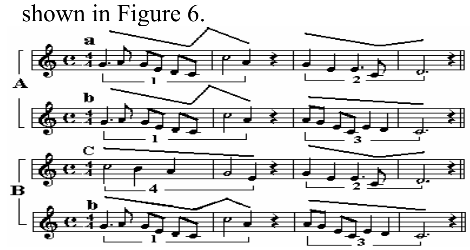
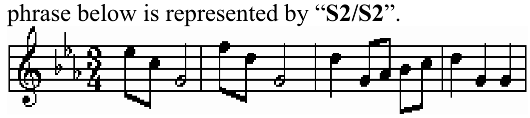


Figure 6. The music created by melodic form.

The description of every field in a melodic form is listed below. **a). Melody line:** The melodic line numbers designate the sequential order of melodic phrases. **b). Phrase form:** It is denoted by the lower case letters a, b, c, d, etc. The letter is used to show phrase relationships (same, similar or varied). A phrase that contains a varied motif will be designated by the same lower case letter with additional symbols (+,-,",'number). **c). Phrase Range:** It indicates the highest and the lowest notes of a phrase. **d). Phrase Initial—Final:** The scale degree of the first note and the last note of a phrase. **e). Motif rhythmic pattern:** Consecutive numbers are applied to the sequence of significantly different patterns. **f). Motif contour:** Divisions between motifs are determined primarily by the pauses in a melodic line. In order to show the melodic direction of a motif, For example, the phrase below is represented by "**S2/S2**".



g). Section form: Larger units of melodic form are shown by capital letters, and the same special symbols in the phrase form.

4. The Four-voice Harmonization

To investigate the feasibility of generating melodic harmonization automatically, we restrict the task of harmonizing a given melody as "Basse donnée" or a "Soprano donnée" that are to generate all the allowable chord progressions for given bass or soprano sequences, as shown in Figure 7.

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Figure 7. An example of a choral created from the tabular constraint.

We made modification on figured bass representation by m,n(r)/b, where b is the bass note, r is the root note and m, n are the intervals between two notes. The root of a triad and the bass of a triad are not necessarily the same note. For basse donnée, r is the bass note. For soprano donnée, r is the root note. Based on this notation, we can design Table 1 to check voice leading rules in harmonic theory.

Table 1. Integer figures for checking voice leading rules.

	Chord 1 4,3(0)/0	Interval change	Chord 2 4,3(5)/5	Interval change	Chord 3 4,3(7)/7	Interval change	Chord 4 4,3(0)/0
Soprano	0	0	0	-1	11	+1	0
Alto	4	+1	5	-3	2	+2	4
Tenor	7	+2	9	-2	7	0	7
Bass	0	+5	5	+2	7	+5	0

4.1. Harmonic Progression Form

We reduce the harmonization of a chorale melody to a three stage processes. First, analyze the given melody for segmentation. Next, match a bass against the given soprano. Finally, realize the inner voices by labeling.

Step 1. Segmentation. A segment is a contiguous interval between two partition points. In a song, a phrase often reflects the cycle of human breathing; therefore one complete recording of a whistling tune is considered a phrase. A phrase can be further segmented into two or more motifs.

Step 2. Contour Matching. The soprano and bass (*outer voices)*, define the chorale texture. We must control the relation between the outer voices. The contour relations of soprano and bass are defined as follows: Contrary motion – the voices move in opposite directions, for example, "/" and "\". Oblique motion – one voice remains steady while the other moves (in either direction), for example, "-" and "/". Similar motion – the voices move in the same direction. for example, "N1" and "N2". Parallel motion – the voices move in the same direction while maintaining their distance, for example, "/" and "/".

Step 3. Labeling. The supporting roles for inner voices are realized by labeling. Observing the chord-functions, note assignment rules and chord-progression rules, we apply labels such as cadential forms, function, disposition and chord are used. In our case, each melodic note is given a chord, and each motif is given a cadence. The created harmonic form is shown in Figure 8.

Melody Line	Contour Soprano	Bass	Assignment Soprano	Bass	Cadential Forms
1	V1/N2	V1/N2	O	I	K1
2	N2/V2	N2/V2	O	IV	K1
3	V1/N2	V1/N2	D	III	K1
4	//\	//\	D	VI	K2
5	V1/\	V1/\	S	I	K3
6	V3/\	V3/\	S	II	K1
7	V1/N2	V1/N2	O	III	K2
8	//^2	//^2	O	III	K2

Figure 8. An example of harmonic form

5. Conclusion

As the digital synthesizers, MIDI controllers, have become more popular, there is more demand today for professional MIDI performer or composer. In this article, we have demonstrated that the integration of melody transcription and tabular constraints can allow ordinary users to easily explore his potential in melody creation and harmonization. The contribution are the cost-effective MIDI controller by whistling and interactive algorithmic composition by tabular constraints. Since to learn four-voice harmonization theory by oneself is said to be difficult, we believe that this integration can facilitate computer aided instruction musical system that may judge whether the composition is allowable or not by referring to a set of registered rules.

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