KNOWLEDGE-DRIVEN HARMONIZATION MODEL FOR TONAL MUSIC

Mariusz Rybnik[1] and Władysław Homenda[1,2]

[1]*Faculty of Mathematics and Computer Science, University of Bialystok, ul. Sosnowa 64, 15-887, Bialystok, Poland*

[2]*Faculty of Mathematics and Information Science, Warsaw University of Technology*
Pl. Politechniki 1, 00-661, Warsaw, Poland

Keywords: Musical work, Harmony, Harmonization, Tonality, Knowledge-based systems.

Abstract: The paper proposes an approach to an automatic harmonization of musical work, and is based on the knowledge of music theory. It may be described as knowledge-based, being in contrast to a data-driven approach, that extracts relationships from examples. Our approach emphasizes universality, understood as the possibility of direct model modifications in order to obtain varied harmony characteristics (as for example a complicated and unusual harmony, or a simple harmony using only a small subset of harmonic functions and few modifiers). Therefore it is configurable by changing the internal parameters of harmonization mechanisms (among others: harmonic functions excitements with note pitches, note importance regarding among others horizontal position in measure and vertical position in voices structure, successions of neighboring harmonic functions), as well as importance weights attached to each of these mechanisms.

1 INTRODUCTION

Harmony is an important element of tonal music, it defines the vertical relation between notes, as by definition opposed to *melody* - horizontal succession of notes in specific voice (Sikorski, 2003). In fact, however, the harmonic relations of the leading melody (regarding mono- or homophony) are largely depending on the horizontal succession of notes and intervals between them. In a melody one can frequently detect harmonic passages that follow harmonic chords (with smaller or larger deviations). Similar, but obviously much stronger harmonic relations are to be found in *accompaniment*, where the melody is less (or even not at all) important, as the main goal is to define the background for the leading melody. The obvious exception to these assumptions are polyphonic musical works. They tend to cultivate two or more independent voices, that compete for attention but also have to cooperate harmonically, usually indicating strong harmonic relations.

Automatic harmonization can be seen as a problem belonging to the area of computer music composing. Over the years many various approaches and techniques were used to solve this or similar problems, just to mention a few: Expert Systems (Cope, 1987)(Ebcioglu, 1993), Neural Networks (Hild, 1992), Constraints and probabilistic approaches (Pachet and Roy, 2001) (Pachet, 1995), evolutionary algorithms (Prisco and Zaccagnino, 2009). The common limitation for such approaches seems to be the lack of universality (production of slightly unpredictable results) and (for some techniques) need for large learning database or extensive amount of calculations. Our approach is based on the use of theoretical music knowledge and is aimed at solving these disadvantages.

The paper is organized as follows: Section 2 presents basic concept of harmony in tonal music, Section 3 describes in detail the proposed harmonization model and explains used mechanisms, Section 4 introduces a short example of experimental results. Section 5 concludes the paper, discuses configuration and universality properties and suggests future works.

2 HARMONY IN TONAL MUSIC

The process of creating accompaniment to a lone melody (known as *homophony*) can be divided into two phases. The first is harmonization (creation of harmonic functions and corresponding chords), and the second phase is creation of accompaniment with the use of previously obtained harmony.

Rybnik M. and Homenda W..
KNOWLEDGE-DRIVEN HARMONIZATION MODEL FOR TONAL MUSIC.
DOI: 10.5220/0003889604450450
In *Proceedings of the 4th International Conference on Agents and Artificial Intelligence* (ICAART-2012), pages 445-450
ISBN: 978-989-8425-95-9

Table 1: Harmonic functions related to scale degrees.

Degree	Function			
	Name	Symbol	Shift	
			minor	major
1	Tonic	T	0	0
2	Subdominant 2nd	S_2	2	2
3	Tonic 3rd	T_3	4	3
4	Subdominant	S	5	5
5	Dominant	D	7	7
6	Tonic 6th	T_6	9	8

It is important to stress that in most cases there is no single, ultimate harmony solution for a given melody, usually there are many possibilities, ranging from the simplest and obvious to the complicated and non-trivial ones. The choice depends on the style of music, as well as the capabilities of instrument/orchestration and the abilities of performers/harmonizers. There are also cases, when no additional information, except for the leading melody and harmonic functions, is needed to perform the music. Common example is improvised *à vista* accompaniment to songs, when playing the guitar or piano.

For the purposes of this paper we have focused on a tonal system with two basic scales: major and minor (*natural minor* as well as *harmonic* and *melodic* modifications). Our considerations and experiments are based on six harmonic functions (built on 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} grade of major/minor scales) with basic modifications: adding seventh (minor and major), ninth (minor and major), sixth (minor and major). We have omitted *incomplete Dominant seventh* built on grade 7^{th} as being equivalent to *Dominant seventh* with omitted root, alterations and higher intervals (alike eleventh, thirteenth), that may be seen as dissonances that are meant to *resolve* (and enrich harmony), rather than integral harmonic modifiers. The tonal harmonic functions along with names and symbols are presented in Table 1.

3 PROPOSED HARMONIZATION MODEL

The proposed harmonization model is based on several mechanisms, that are supposed to closely follow music theory:

1. **Particular notes have various harmonic importance**,
2. **Each note may excite (fit to) one or several harmonic functions** based on its pitch and considered function components,
3. **Some harmonic functions are more likely to occur than others** (the most popular example being *Tonic* - a base and consolation for vast majority of tonal music), therefore it is preferable to prioritize functions being more frequently used,
4. **Specific harmonic functions' successions are more or less probable**, therefore it is possible to support more likeable (frequent) successions (alike *Dominant* $\rightarrow$ *Tonic* or *Tonic* $\rightarrow$ *Subdominant*).

The mechanisms are implemented in possibly independent way and weighted (using a range $[0;1]$) in order to easily configure the degree of influence (or eliminate the influence at all) on the final harmonization, in comparison with the other mechanisms.

3.1 Data Representation of Harmonic Functions

Each harmonic function is stored in a structure that contains a vector (of length 6, as we consider 6 different diatonic functions) of *Harmonic Function Strengths* and a corresponding vector of modifiers. In our experiments the modifiers are mostly limited to *sevenths*, with occasional *ninths* and in rare cases to *sixths* (*sixth* is present in so-called *Chopin chord*: *Dominant* with *seventh* and natural or augmented *sixth* instead of *fifth*, resolving down to first degree of scale). The diatonic function with modifiers is equivalent to chords i.e. *Tonic* with modifier *seventh* in key G-major is equivalent to G^7. Some modifiers cover others, i.e. a chord with *ninth* is supposed to gorge a chord with *seventh*.

Musical piece is decomposed into elementary harmonic fragments (defined as indivisible musical piece unit with one diatonic function attached to). For experimental evaluation we have chosen fragments of fixed lengths at the most two beats or less depending on the *time* of musical work, i.e. for the time $\frac{3}{4}$ it would be two beats for the first harmonic fragment of measure and one beat for the remaining fragment of measure; for the time $\frac{2}{4}$ one harmonic fragment per measure would most probably be sufficient. Each harmonic unit is processed independently - with exception of supporting specific successions of harmonic functions (see Section 3.6) - therefore it does not require additional modifications, as shorter harmonic fragments will also naturally have lower influence on larger neighbors. In most cases this simplistic division would be sufficient, as harmonic functions rarely change in practice more frequently, while over-fragmentation could result in lower accuracy of harmonization.

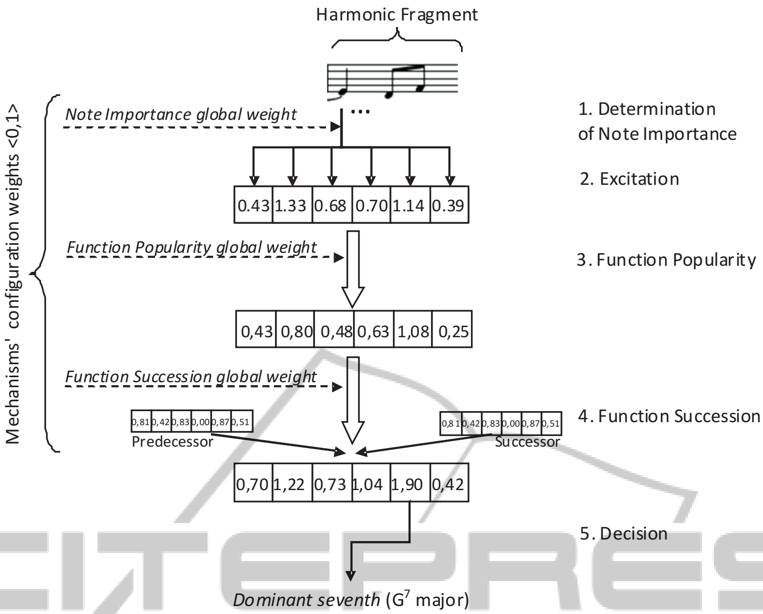

Figure 1: Harmonization model flow.

3.2 The Flow of Proposed Model

The flow of proposed model for an exemplary *harmonic fragment* is presented in Figure 1, and proceeds as follows:

1. The harmony of particular fragment is evaluated by examining all notes from this fragment. Each note is attached with *Note Importance weight* according to the exemplary set of rules from Section 3.3.
2. Each note excite (add a value to *Function Strengths* vector) one or - in most cases - few corresponding diatonic functions by being a specific chord component, with degree defined by a *Function Excitation Matrix* (Section 3.4).
3. When all the notes are evaluated the vector of a *Function Strengths* is element-wise multiplied by a *Function Popularity Vector* (Section 3.5), what primarily acts as encouragement for more popular functions. It may also be used to serve a different purpose, if one wishes for a rich and uncommon harmony).
4. After all harmonic fragments are evaluated, the mechanism for supporting particular function successions is applied. The degrees of desire for a specific succession of harmonic functions are defined in a *Function Succession Matrix* (Section 3.6). They serve as an additional modifiers for vectors of the *Function Strengths* with regards to direct predecessor and successor. The modification occurs twice for every fragment (except for the marginal fragments), the first time as a predecessor, and the second time as a successor. The modifications are calculated for each function succession possible (a total of 36 combinations possible for 6 recognized functions, modifiers not taken into account) and are multiplied by both corresponding function strengths and additionally by a $1/12$ factor in order to keep them in the original *Function Strengths* range.
5. After applying the succession modifications a decision (of type winner-takes-all) is made for each Harmonic Fragment, based on values of the *Function Strengths*. The winning diatonic function is translated into chord, depending on the *key* and attached with chord modifiers (i.e. *seventh*, *ninth*) stored during *Excitation*.

Each omitable mechanism (*Note Importance, Function Popularity, Function Succession*) is attached with an overall *Global Configuration Weight* from the range $[0;1]$ (as seen in Figure 1), that may be used to fine tune or disable the influence of these mechanisms on the final harmonization result. *Excitation* is the essential mechanism to obtain the *Function Strengths*, therefore it is not weighted in similar manner. The mechanisms are based on matrices (*Excitation*, *Function Succession*), vectors (*Function Popularity*) or rules (*Note Importance*) that offer many substantial and direct configuration possibilities.

Table 2: Determining note importance.

Condition	Importance
Note at the end of a tie	0.4
Note on the 1^{st} beat	1.0
Note on the 3^{rd} beat	0.9
Other notes	0.6

3.3 Notes Importance Determination

For determining notes importance we have considered:

- **the position in measure** - notes *on-beat* (at inherently accented parts of measure) are very important (especially 1^{st} beat and a little less 3^{rd} beat for time $\frac{4}{4}$), while *off-beat* (at generally unaccentuated parts of measure, as for example 2^{nd} and 4^{th} for time $\frac{4}{4}$) are less significant. Notes occurring in-between these main beats are harmonically least important.
- **the notes that are at the end of ties have minor contribution to the harmony**, because when played on string instruments (among others: grand piano, upright piano, guitar) they are not hit again,
- **the long notes are usually more important than the short ones**,
- **the notes that are easily-heard by human ear are placed in extremal voices** (highest and lowest notes), the notes in the middle voices are harder to hear and therefore contribute less to the harmony of musical work,
- **accentuation increases the volume and the harmonic value of the note**.

For the experimental evaluation we have determined a set of the note importance rules as described in Table 2. As we deal only with a single melody we neglected the voice position (not relevant in this case) and length of notes (do not contribute a lot in this case), which would be however important for music works with many melodic parts.

3.4 Implementation of Tonal Functions Excitation by Notes

In order to define diatonic functions we had to detect the *key* of musical work, that may be obtained in simplified but effective method, by analyzing the pitch of the last note in the leading voice and the *key signature*. This is possible due to the fact that in vast majority of cases melody ends on 1^{st} degree of tonic scale, being the *resolution* of tension. There are only marginal exceptions to this scheme (disregarding *modulations*).

In order to define the excitation of diatonic functions by the notes occurring in the melody or the accompaniment we have defined a table of excitation (Table 3), where each diatonic function may be excited by particular note with a specified degree. This is relative to the pitch of the note in question, as well as the pitches of the notes occurring in the tonal functions themselves. We have defined the degree of excitation in the range of $[0,1]$, assigning:

- greater degrees $[0.8;1.0]$ to the most typical chord components as *root note*, *third* and *fifth*,
- moderate degrees $[0.4;0.6]$ to less specific components: *sixth*, *seventh*, *ninth* with ,occasional modification of natural *third*, that serves making major chords from naturally minor chords, what serves mostly as *tonicization* (local *Dominant* $\rightarrow$ *Tonic* resolution)
- small degrees $[0.1;0.2]$ to rare modifications of natural *sixth* and *seventh*, *ninth*.

A similar table has been prepared for minor scales, the obvious differences are the natural qualities of diatonic functions, the less obvious would be frequent conversion from naturally minor *Subdominant* and *Dominant* to major ones (occurring commonly in *melodic* variation of scale and partially in *harmonic* variation).

3.5 Function Popularity

The goal of determining function popularity is to directly prioritize frequently occurring tonal functions (like *Tonic*, *Subdominant*, *Dominant*) and in this way enforce them to occur more frequently than less popular derivative ones. The goal is indirectly obtainable by using lower coefficients in the *Functions Succession Matrix* (described in Section 3.6), but it is obviously easier to control directly. For experimental studies we have used the *Function Popularity Vector* as specified in Table 4.

3.6 Succession of Harmonic Functions

The succession of harmonic functions (horizontal relations between neighboring harmonic functions) is implemented using encouragement of more probable combinations, with moderation of less likable ones. This is done using a matrix of *Functions Succession*. The exemplary matrix for major scale is presented in

Table 3: Table of excitation for major scales.

	Absolute shift from function *root note*[in semitones]											
	0	1	2	3	4	5	6	7	8	9	10	11
T_6	1.0	0.0	0.0	0.9	0.1	0.1	0.0	0.8	0.0	0.0	0.4	0.0
D	1.0	0.5	0.2	0.1	0.9	0.1	0.0	0.8	0.0	0.4	0.6	0.1
S	1.0	0.0	0.0	0.1	0.9	0.1	0.0	0.8	0.0	0.0	0.4	0.0
T_3	1.0	0.0	0.0	0.9	0.1	0.1	0.0	0.8	0.0	0.0	0.4	0.0
S_2	1.0	0.0	0.0	0.9	0.1	0.1	0.0	0.8	0.0	0.0	0.4	0.0
T	1.0	0.0	0.0	0.1	0.9	0.1	0.0	0.8	0.0	0.0	0.4	0.0

Table 4: Function popularity.

Tonal function	
Name	Popularity
T	1.0
S_2	0.6
T_3	0.7
S	0.9
D	0.95
T_6	0.65

Table 5: *Functions Succession Weights* for major scales.

	Transfer into:					
	T	S_2	T_3	S	D	T_6
T_6	0,4	0,8	0,3	0,8	0,7	1,0
D	0,9	0,4	0,7	0,3	1,0	0,8
S	0,7	0,4	0,4	1,0	0,9	0,5
T_3	0,3	0,2	1,0	0,5	0,6	0,8
S_2	0,2	1,0	0,2	0,5	0,9	0,4
T	1,0	0,4	0,3	0,8	0,9	0,6

Table 5. The matrix for minor scale is very similar and therefore not presented here.

The values in the matrix were determined in order to prioritize most likable successions, like *cadence*, but also allowing more complicated successions It is worth mentioning that the most supported quasi-succession is maintaining the current function (no change) with maximum degree of support: 1.0. That allows more efficient handling of the common case where harmonic functions change less frequently than hard-coded (in our experiments) two beats. It is also important to mention that the support of succession occurs only between harmonically determinable half-measures, excluding these that do not contain notes at all (only pauses) or contain only ongoing tied notes from previous beats. It is assumed that such fragments continue the previous harmonic function (which is a slight oversimplification as it does not have to be always true). The succession support occurs forwards and backwards with a degree defined by the sum of products of the neighboring *Function Strengths* and a succession weight from the *Functions Succession matrix* for each possible succession.

4 EXPERIMENTAL RESULTS

This section presents the exemplary results of homophony harmonizations using proposed approach. We have implemented and applied the model to musical works containing a single melody (*monophony*) with no *key* changes, as we considered it more of a challenge (more harmonic uncertainty) rather than using musical works with accompaniment, where harmonic functions are generally much easier to detect (depending on the degree of complication and the purpose of musical work). It is however important to stress that the proposed harmonization model remains viable for almost every musical piece, regardless of number of voices, as long as it is maintained in tonal system i.e. uses either major or minor scale (possibly with slight modifications). Use of higher number of voices (chords) would ideally require a customized *Notes Importance* determination (as described in Section 3.3), in order to detect and prioritize more important voices and attenuate the less important ones. Efficient harmonization of musical works with key changes (known as *modulations*) would require detection of such changes and adequate updating of tonal base and/or minor/major properties.

The results in Figure 2 present two different harmonies for a short homophony fragment. The functions and chords at the top were obtained for global configuration weights (respectively: *Notes importance, Function popularity, Functions Succession*) equal to $[0.4, 0.4, 0.4]$, while at the bottom with global parameters $[0, 0, 0.8]$. In the first case the less popular functions are moderated, while in the second one the less popular functions are present and there is more continuity in successions. A change of global weights alone - without the modification of the inner parameters - gives different and interesting results.

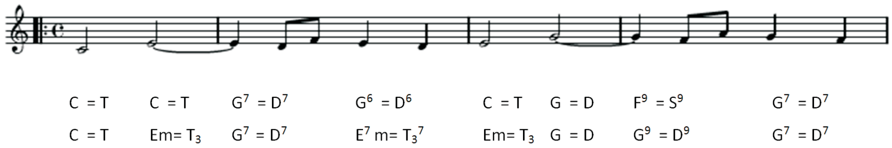

Figure 2: Two different harmonizations for a homophony fragment.

5 CONCLUSIONS AND FUTURE WORKS

In this paper we have presented the harmonization model based on the knowledge of music theory. The main goal of this approach is achieving universality and obtaining direct control over various harmonization mechanisms. It is important to stress the configuration possibilities and universality of the proposed model: as it is not data-driven but knowledge-driven, it provides the ease of control of the behavior and, to some extent, results of harmonization. As opposed to the data-driven approaches (taught with examples) our methodology does not need to be fed with large or representative sample of data (requiring data gathering, selection and often producing hard to control results). It may be used in many variants relying only on the theoretical knowledge. With modifications of underlaying configuration data one can try (and in some cases be guaranteed) to achieve multiple valuable tasks, such as:

- defining the *Note Importance* rules tuned to various musical pieces;
- defining the *Function Excitation Matrix* to easily generate very rare or very simple functions/modifications;
- defining the *Function Popularity Vector* to moderate, forbid or encourage specific tonal functions;
- defining the *Function Succession Matrix* to moderate, forbid or encourage specific harmonic function successions;
- changing the *Weights of Harmonization Mechanisms* in order to tune the model to the specific needs and expectations;
- iterate through various configurations in order to quickly generate various (possibly interesting) harmonies for the same musical work.

Future works in the area will be conducted in the following directions:

- development and evaluation of presented harmonization model,
- developing criteria for evaluation of obtained harmony,
- automatic parametrization of the harmonization model based on the above-mentioned evaluation,
- determination of configuration matrices and parameters for the different *styles* of musical works, like jazz, classical music, popular music, etc.
- accompaniment generation based on the harmony provided by model,
- existing accompaniment modification and enrichment based on the independent harmony provided by model.

REFERENCES

Cope, D. (1987). An expert system for computer-assisted music composition. In *Computer Music Journal*, volume 11 (4), pages 30–46.

Ebcioglu, K. (1993). An expert system for harmonizing four-part chorales. In *Machine Models of Music*, pages 385–401. MIT Press.

Hild, H. Feulner, J. M. W. (1992). Harmonet: A neural net for harmonizing chorals in the style of j.s. bach. In *Advances in Neural Information Processing 4*.

Pachet, F. and Roy, P. (2001). Musical harmonization with constraints: A survey. In *Constraints Journal*, volume 6(1), pages 7–19. Kluwer Publisher.

Pachet, F. Roy, P. (1995). Mixing constraints and objects: a case study in automatic harmonization. In *TOOLS Europe '95*, pages 119–126. Prentice-Hall.

Prisco, R. D. and Zaccagnino, R. (2009). An evolutionary music composer algorithm for bass harmonization. In *Applications of Evolutionary Computing*. LNCS.

Sikorski, K. (2003). *Harmony part 1 and 2 [in Polish]*. Polskie Wydawnictwo Muzyczne.