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Computer search tool for harmonic structures and progressions in MIDI files and possible applications

Abstract
This article explains the principal features and qualities of tonality in music, defines harmonic functions, closures and cadences. In the second section, the structure and work of Harmanalysis software is explained in three phases: (1) chord analysis (searching for chords and their types as chord classes – also in inversions, in a vertical/horizontal direction); (2) determining the key (the current key in a given section of the composition or identifying tonally unclear sections); and (3) assignment of harmonic functions to the ascertained chords and keys. The article displays the findings of analysis in: a) the Sibelius notation layout, b) shows how the frequency of occurrence of chords, keys and harmonic functions may be displayed in a tabular format. The results are also indicated via a number of statistical assessments in a processed specimen of 5 sets of compositions in three genre fields: (1) classical music (songs by Franz Schubert and Ján Levoslav Bella); (2) popular music (songs of well-known pop music); and (3) folk music, adapted by Miloslav Francisci and Vladimir Rebikov. In conclusion, there is a concise summary of a variety of possibilities for acquiring new information by using computer analysis of harmony. With the advantages of computer processing, these approaches may enable a complete analytical and comparative processing of the work of a prolific composer, or a detailed analysis and comparison of large sets of diverse compositions (of differing styles and genres), on condition that they are encoded in MIDI format.

Key words: computer analysis of harmony; tonal cadence cycle; plug-in in notation software; statistics; music style; music genre
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1. HISTORICAL INTRODUCTION
Since the crystallisation of tonal functional harmony from modal, tonal harmonic structures and relationships have contributed in considerable measure to dynamising the process of the musical composition. Such a process may be metaphorically compared to undulation, emerging via incessant changes of the feeling of tension. When listening to tonal music, a feeling of the change of tension arises with a progression of chords which are bearers of centripetal or centrifugal forces and are expressed by tonal harmonic functions. The first indications of the raising of harmonic tension and its subsequent relaxation came when local elevations of the penultimate notes in the melody of the work/part or phrase from it, were introduced into old modal music. Composers, attempting to evoke a sense of the conclusion of a musical section, discovered by experience how this might be achieved. The tendency of the seventh degree to ascend by a step of a minor second towards the fundamental (eighth and thus first) degree of the church mode, if it occurs in the penultimate sounds of the composition, produces a harmonic progress that creates a feeling of conclusion. The concluding feeling of a

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lowering of tension emerges more strikingly when an ascending seventh degree (as the 'leading tone') concludes the process to the eighth/first (hence fundamental) degree in the highest voice of the melody (in 'soprano'). It is stronger if simultaneously the lowest voice ('bass') proceeds by a fifth leap downwards from the fifth degree to the fundamental/first degree. If in the mode the natural minor second did not occur between the seventh and eighth ('finalis') degrees (that was not customary in the current mode), composers began to raise the seventh note in the composition with an accidental to achieve an artificial leading tone (called 'musica ficta'). In modal static music the germ emerged of the later dynamic tonal technique of conclusion. Frequent and regular harmonic conclusion introduced into tonal music, as opposed to the static process of modal music, a harmonic dynamism of changes of tension that were perceived by the listener.

The changes of tension proceed in waves of alternation, where intensifying tension (through the harmonic function of the subdominant, tending towards the most dynamic harmonic function of the dominant) gives way to a relaxation of tension (with the ascending resolution of a leading tone, which had a tendency to advance) and to the final fundamental degree (in modal music 'finalis', in tonal music 'tonic').

'Musica ficta', as the raising of the seventh (penultimate) degree of the (static) mode, may be regarded as one of the first expressions of the rebirth of modal harmonic thinking as tonal, based on the empirical discoveries of composers. Subsequently, the tonal-functional harmonic system (evolved from modality), where the chords formed on the individual degrees of the tonal scale are bearers of varying degrees of centrifugality (from the tonic) and centripetality (to the tonic), has capacities to raise or lower the feelings of tension by the specific utilisation of their sequencing, tending and resolving. Therefore the tonal-functional system is regarded as dynamic.

2. RESEARCH GOAL

One of the most important principles of expression in tonal music is tension-changes in harmony. This is done by the organization of pitches, where one of them is perceived by the audience as a centre (tonic). Other structures/chords have a relationship to this centre according to their harmonic function. The harmonic function represents the force of the chord, leading either to the centre as a dominant function, or away from the centre as a subdominant function. Increasing and decreasing of harmonic-tensions in specific chord progressions is known as 'cadence'. According to the *Harvard Concise Dictionary of Music* cadence is a '...harmonic formula that occurs at the end of a composition, section, or phrase' (RANDEL 1978, p. 75).

In line with this definition, our software finds cadences in tonal compositions to discover particular types of cadences. Using these, it is possible to define the formal structure of the analysed composition. In connection with statistical evaluations of the use of particular cadence-types, the particular music-style is characterized (style of the historical epoch, music genre, style of the particular composer, or of the music form, etc.). In addition, we compare the frequencies of the chord classes which occur, and compare the preferred harmonic functions, the types of cadences in different music styles, the constitution of various harmonic functions, their lengths, the frequency of their occurrence in compositions, etc.

3. HARMONIC FUNCTIONS

The concept of 'harmonic function' originated in connection with the degree of the key, on which the root of the chord was formed (as different chord classes – triads, later also as seventh or ninth chord, see Table 1).

According to Hugo Riemann, one of the most important theoreticians of modern functional harmony, all chords which sound in tonal music as vertical, and also horizontally disposed (spread) third harmonies, have harmonic functions. The principal (and basic) functions are normally referred to as T (tonic) chords formed on the first degree, D (dominant) formed on the fifth degree, and S (subdominant) formed on the fourth degree, of the relevant tonal scale. The chords formed on other degrees may substitute these functions, depending on which two notes of the principal functions they contain. At the same time, the principal functions are the only triads which have a genus conforming to that of the relevant key (in the Major key T, S, D = major triads, in the minor key T, S, D = minor triads). The triads formed on the other degrees of the Major and minor scales do not conform in genus of the key, but they may represent (and substitute) the principal functions – and the composers employed them for that. By using both the principal and the subsidiary harmonic functions, the composers created a dynamised musical process, which was developmentally ever more complicated. They increased the vertical harmonies from triads even to five- and still higher multi-note chords. Also increased were

the numbers of the leading tones in one chord, either by using tonicizations or by altering the tones of the chords to have more (artificial) leading tones. Furthermore, there was an increase in the number of members (chords) of the cadence, from a simple four-member (in the progression of harmonic functions I/T–IV/S–V/D–I/T) to a multi-member, where a progression of several chords could represent each function. (For example, composers could create a subdominant by a gradual progression of chords formatted on the fourth-second-sixth degree, where all three degrees include at least two notes from the principal/basic function of the subdominants, and therefore all three created a subdominant member of the cadence). There are theories that on the subsidiary degrees composers used chords of mixed functions, which according to need or according to the harmonic environment could substitute alternately for several functions, either two, or in the case of five-note chords, also three. (This theory was systematically constructed by the Slovak musicologist Miroslav Filip, see FILIP 1997.)

Table 1: **The principal and subsidiary functions, dependent on the degrees of the Major/ minor scales**

I. degree – **principal** function – **centre** – Tonic (symbol T)
II. degree – mixed function 'sd', **subsidiary centrifugal,** substituting for the principal function of the subdominant – symbol S, in the form of four-note as S+6 – the 'Rameau subdominant' with an added sixth (e.g. in C Major including notes f–a–c–d), or S7, as a *half-diminished seventh* (e.g. in C Major including notes d–f–a flat–c)
III. degree – mixed function 'td', **subsidiary**, according to context either **centripetal** (substitution of D – symbol Đ), or also **substituting the centre** (substitution of T – symbol Ŧ). The logical progression of functions, from tonics through the subdominants to the dominants and from those to the tonics, helps us to determine the functional significance of that chord in the real composition. If the composer has used a chord on the third degree after the subdominant and resolved to the tonic, this chord has a dominant significance; but if before this chord the tonic sounds, and the subdominant after it, then it has the significance of a variant of the tonic as Ŧ.
IV. degree – **principal** function **– centrifugal** subdominant (symbol S)
V. degree – **principal** function, with the highest degree of tension, **centripetal** dominant (symbol D), tending to T
VI. degree – mixed function 'ts', **subsidiary** function, either **substituting the centre** (symbol Ŧ), if D stands before it (in such a position it creates a *deceptive cadence* in the progression of D–Ŧ), or **centrifugal** function substituting the subdominant (S), if it is resolved into the dominant.
VII. degree – mixed function 'ds', **subsidiary** function, substituting the dominant (Đ) as a **centripetal** in the root position, and in the first inversion, as it is predominantly resolved to tonic. It may be formed as a **centrifugal** function substituting the subdominant in the case of a seventh chord in the second and third inversion, while the bass note can be regarded as a functionally determining subdominant especially if it proceeds further to the dominant.

If a particular chord class is formed frequently on a specific scale degree and the composer uses it regularly in cadence progression, it may also be an important style feature (either consciously or unconsciously) of the composer's musical language. (For instance Ludwig van Beethoven used many times the second inversion of the tonic between the subdominant and dominant function as a cadence of five members: I–IV–$I^{4/6}$–V–I). This gives an audible specific intonation to the composer's style.

The statistical account of the occurrences of chord class structures in cadence can only be done using a computer, as there are a huge amount of them in every composition. For the identification of the harmonic function of every chord class which occurs, it is first necessary to determine the current tonal key. The key may change (sometimes many times) during the composition Therefore, it is possible to identify the scale degree on which the chord class is formed after the determination of the first tonal key as well as after every change of it during the whole composition.

4. ENDING CLOSURES AND CADENTIAL CYCLES

Closure techniques are traditionally regarded as one of the most important confirmations of the current tonal centre. The tonal key (major or minor) is determined by the closure in particular where there is a tri-functional cadence process (as an unambiguous ending). A tonally significant closure, according to many authors, could be the bi-functional closure in the progression V–I degree (authentic cadence), alternatively IV–I degree (as plagal cadence). According

to Burton S. Rosner and Eugen Narmour, the progression IV–I appears to some writers (e.g. Riemann, Schenker, Schoenberg) to be too weak, while others compare it to the progression V–I (e.g. Bernstein, Morris, Meyer). Rosner and Narmour point to the fact there are no empirical proofs confirming either the equivalence of closures IV–I and V–I or their complete difference (ROSNER and NARMOUR 1992, p. 384).

Several theories which assert that not only the progression of harmonic functions, but also the further musical procedures 'scale step, soprano position and bass inversion', all contribute to the listeners' feeling of closure, have not been psychologically and empirically confirmed (ROSNER and NARMOUR 1992, p. 386). These authors have adduced psychological research to support the theory that the harmonic schema of the closure is perceived in the progression of chords V–I (functionally D–T), alternatively III–I and ultimately VII–I (in both cases functionally with the significance of the chord at degrees III and VII as substitute dominants, also Đ). They have also confirmed the weak perception of the progression IV–I in the context of closure.

For these reasons we will continue to regard the duads V–I (D–T), III–I (Đ–T) and VII–I (Đ–T) as the closing duads of the harmonic degrees (or functions), but we will continue to hold the view that the most powerful cadences are of three members (alternatively of four, if their schema begins with degree I/T, or also of five members with a second inversion T, in process of cadence mediately before the function D, as is explained further), adduced e.g. by. Walter Piston (PISTON 1987), Miroslav Filip (FILIP 1997), and also by Dmitri Tymoczko (TYMOCZKO 2010, p. 58). Tymoczko designates the cadential progressions as 'harmonic cycles' and presents ten variants of the most frequented cycles in Johann Sebastian Bach and sixteen variants of harmonic cycles in Wolfgang Amadeus Mozart, also giving their frequency of occurrence in the compositions examined.

To justify the preference in a tri-functional cadence for the three-to-five-member structure of harmonic functions, presenting the strongest harmonic cadences, one may adduce the statement by Walter Piston (PISTON 1987, p. 172):

> 'There are no more important harmonic formulae than those used for phrase endings. They mark the breathing place in music, establish or confirm tonality, and render coherent, the formal structure...The harmonic formula V–I the authentic cadence, can be extended to include the II or IV that customarily precedes it. We now also have the cadential six-four, the double appogiatura over a dominant root, whose function is to announce the cadence. Thus a final cadence incorporating these preparatory elements in order, as II^{6}–$I^{4/6}$–V–I or IV–$I^{4/6}$–V–I, will be harmonically very strong.'

Apart from the two strong cadences mentioned above, we have also added in, as equivalent cadences, those which use further subsidiary harmonic functions in such a way that each principal function may be substituted by a subsidiary or progression of subsidiaries which contain two notes from it (according to Table 1, see above). Most of these latter may be found among the cadences used by Mozart (TYMOCZKO 2010).

For completeness, we mention all of the strong cadences (Table 2) for which the programme searches. The search for cadences takes its course with two initial steps: firstly, determining the incidence of the chord classes as superpositions of thirds; and secondly, identifying the key (major or minor) which applies in the given section of the composition (there could be several changes of the current key during the progression of the whole composition). After a third step, allocating the harmonic functions to the individual chords, the programme indicates the sequentiality of those progressions of theirs which create cadences.

T – II (as S̶, or S̶$^{(7)}$) – $T^{4/6}$ – $D^{(7)}$ – T
T – S – $T^{4/6}$ – $D^{(7)}$ – T
T – VI – $T^{4/6}$ – $D^{(7)}$ – T
T – $II^{(7)}$ – $D^{(7)}$ – T
T – S – $D^{(7)}$ – T
T – VI – $D^{(7)}$ – T
T – S – $T^{4/6}$ – Đ$^{(7)}$ – T
T – $II^{(7)}$ – $T^{4/6}$ – Đ$^{(7)}$ – T
T – VI – $T^{4/6}$ – Đ$^{(7)}$ – T
T – $II^{(7)}$ – Đ$^{(7)}$ – T
T – S – Đ$^{(7)}$ – T
T – VI – Đ$^{(7)}$ – T

Table 2: **Harmonic formulas detected by the Harm-analysis program as the main cadence cycles**

D7 is predominantly used as a major-minor seventh. The S7 (on the second degree) functions are predominantly used as half-diminished seventh chords, Đ7 (on the seventh degree) functions are predominantly used as diminished sevenths. This means they are built up in harmonic-tonal keys (i.e. in a minor key sharp with seventh degree and in a major key flat with sixth degree).

Every function may also be used in an inverted position except the last one. The inversion of the last tonic gives a weaker feeling of the ending of the phrase (or section / composition). Other non-traditional cadences may be looked for as sequences of various harmonic functions between two identical tonics.

5. CHORD CLASS, TONAL-KEY

5.1. Chord class

The idea of establishing a 'chord class' is inspired by Forte's idea of 'pitch class' (FORTE 1973). This is the stable structure of a vertical or horizontal compound sound (arpeggiated or spread in melody), where its structure is based on distances of thirds, measured upwards from the root and expressed by the number of semitones between neighbouring tones (three semitones for a minor third and four semitones for a major third). In classic harmony textbooks, a system of names and symbols for the description of these chord classes is established (see Table 3, according to PISTON 1987 and to FILIP 1997). It does not matter in which octave and how ordered the tones are in the music space, the particular chord class is the same, differing only in its position (root or inverted).

Table 3: **Chord classes: structures, names, symbols**

Semitones from the root	Chord name	Chord symbol
4–3	Major triad	+ (or Maj5)
3–4	Minor triad	- (or Min5)
4–4	Augmented triad	++ (or Aug5)
3–3	Diminished triad	-- (or Dim5)
4–3–3	Dominant seventh	D7
4–3–4	Major seventh	Maj+7
3–4–3	Minor seventh	Min-7
3–3–3	Diminished seventh	Dim7
3–3–4	Half-diminished seventh	Dm7
4–4–3	Augmented seventh	Aug7
3–4–4	Minor-major seventh	Min+7

5.2. Tonal key

The organization of musical tones in keys defines tonality

> '[...] in such a way that during the sounding of music, various changes of tension arise in the piece, resulting from various centralizing and decentralizing devices. We are speaking here about the centrifugal and centripetal forces. Centralization is a musical device by which one tone, or one interval or one chord can become a centre for the listener during listening, i.e. the most important tone/interval/chord, to which all music is steered, in which it can calm down, stabilize. The central chord is the chord of harmonic peace'

and the harmonic function of this is known as the 'tonic' for a particular tonal key.

> 'Work with tonal forces is only possible in the twelve-tone equal temperament of European music. Various tensions and changes of these centralizing forces were attained by composers with the help of application of "harmonic function" of chords and their sophisticated progression.' (FERKOVÁ – KAČIC 2018, p. 38)

The tonal key is presented at the beginning of every section/staff of the score with the key signature (a specific number and accustomed order of sharps/flats, which systematically shifts a particular pitch class).

6. ALGORITHM

Compositions are inputted into software as MIDI files. The algorithm detects and determines chord classes, the major/minor key at the beginning (and in every noted change) and finally names of harmonic functions. The process has three phases and the results can be viewed using

notating software Sibelius. The analysis software can be implemented into various notating software as a plug in – this is also part of the solution.

6.1. The first phase – chord class analysis

The software reads the MIDI file, transforms it into a more suitable format that allows the program to work with higher level structures, such as measures (bars), measure sections and beats as well as information about the current time and key signatures. The program then iterates beat after beat and/or measure after measure. Each measure is read and possible structures of chords are found. These are compared with each other and the weight of chord tones, probability and other factors is taken into consideration. Each measure can be divided into simple measures, if needed (e.g. 6/8 time signature, into two 3/8), or into individual beats, which allows better chord detection. To further refine detection, we sought to eliminate melodic tones by taking into consideration beat length and the prevailing length of only chord tones in the measure. If there is an arpeggiated chord (chord spread over more beats) used in the analysed composition, the program is able to find this, and the beats can be connected if there is no vertical structure of chord class detected on the separate beat. The connection of tones for identification of an arpeggiated chord is bordered by bar lines.

6.2. The second phase of the program – detection of the key

The software uses results specified and gathered by chord analysis and additional information from the score, such as key signature and local accidentals/new MIDI numbers. If the key signature is known at the beginning, the major/minor key pair is found and confirmed or rejected by the corresponding major or minor triad at the beginning. Then program iterates over measure sections or beats. It reads tones and detected chords and reacts to the current chord and tone. For each situation, the program has a defined process. The process determines the key, or if no key is detected, the program is instructed to move to the next measure section after the processed part of the score. Certain chord classes can determine a major/minor key pair, and here we need to find a confirmation of one of them further on in the score. Some chord classes identify key/scale directly. (Namely the dominant seventh-chord, half-diminished seventh-chord or diminished seventh-chord). If the key is known during score processing, we can assign the same key up to the moment a tone outside from the key (a new MIDI number) is found in the measure section. We then seek its confirmation (whether the tone belongs to a chord and is repeated in more beats or measures) and apply the known process for chords that determines the key. If we are not able to find the key by using the above processes, we try to detect the scale structure by looking at the closest group of seven chord tones to see if they form a major/minor scale. The major scale structure in an ascending direction is (in the number of semitones between neighbouring degrees): 2–2–1–2–2–2–1. The minor (harmonic, which is predominant) scale structure is: 2–1–2–2–1–3–1. (the natural – or Aeolian – minor scale structure is the same as the major, but shifted to start from the sixth degree, i.e. 2,1,2,2,1,2,2. Here the most important relation is missed, the leading tendency to centralise from the seventh degree to the eighth/first tone. Therefore, in the minor key it is common to augment the seventh degree of its scale and in this way to diminish the last major second – of two semitones – to minor second – of one semitone – as leading seventh degree to the central tonic).

6.3. The third program phase – harmonic functions identification

The software utilises key and chord analysis calculated in the former two phases. The tonal/harmonic functions are identified according to the scale degree of the key on which stands the root of the detected chord class. This allows the determination of functions such as tonic, dominant, sub-dominant and their substitutions, etc. This gives us important data for the discovery of cadencies, patterns and the style of the music in the score (as in TYMOCZKO 2010). The proposal of the denotation of harmonic function according to the scale degree (in the tonal key) of the root of the particular chord class is given in Table 4 (for more information, see FERKOVA 2017a).

Table 4: **Chord classes as possible harmonic functions**

Degree of the scale	Possible chord classes on this degree	Possible harmonic function (main or substituted)
I	Major or minor triad	T
II	Minor, diminished triad, half diminished 7th, minor 7th chord	's' or 'd' as collateral / substituted functions
III	Minor or major triad or minor or major 7th chord	'd' or 't' as collateral / substituted functions
IV	Major, minor triad, major, minor 7th chord	S
V	Major triad, D7	D
VI	Major or minor triad, major or minor 7th chord	't' or 's' as collateral / substituted functions
VII	Diminished triad, diminished 7th, half-diminished 7th chord	'd' or 's' as collateral / substituted functions

7. PRESENTATION OF THE OUTPUT

The output of the analytic process of the program can be viewed as a Sibelius layout of the score of the analysed compositions. This also allows to check how the software detected the vertical/horizontal chord class structures and whether a tonal key is identified (if possible). The symbols of chord classes are located under the bottom staff of the section. The character symbol for no detected chord is '0', for missing key is '?' (if the software is not able to determine a key in a particular beat), or is the name of the centre (tone) key in upper case for the major or lower case for the minor key. Assignments of identified harmonic functions for detected chord classes are located after its name and the symbol '/' – their names are given in Table 1 above. Where '?' is stated, it was not possible to detect a chord class, or the software was not able to determine a key. Without both these pieces of information, the harmonic function cannot be determined. The Sibelius plug in allows also the switch over of chord class symbols and/or harmonic function symbols.

8. MATERIAL FOR TESTING

To check the effectiveness and universal application of the software use for various purposes, we collected 5 sets of songs by several composers from diverse musical genres.

The examined song sets are MIDI files, which were analysed automatically by computer. Some files were downloaded from https://www.classicalarchives.com/ (Franz Schubert), others were read by computer from score sheets (Miloslav Francisci, Vladimir Rebikov) using PhotoScore software. Others were downloaded from websites (popular music), and files of Ján Levoslav Bella's songs were taken from other research (by GRICH 2013).

8.1. 90 + 13 Slovak folk songs

adapted for piano by the Slovak-American composer Miloslav Francisci (1854-1926) represent harmonic interpretation of one voice original tunes. The first edition appeared in 1892 (Part I containing 90 chosen from 100 songs, converted by PhotoScore to Sibelius) and 1893 (Part II containing chosen 13 from 100 songs). The used chord classes characterize Francisci's work and showcases his harmonic and musical ideas (FERKOVÁ – URBANCOVÁ 2017).

8.2. 25 Slovak folk songs

adapted for voice with piano accompaniment by the Russian composer Vladimir Rebikov (1866-1920) (see also [10]), originally one voice tunes. The models for piano adaptations by Rebikov were from various printed editions of folk songs from the turn of the 20th century (particularly material from the collection *Slovak Songs I-II*, 1880-1897). A favourite of the composer were love songs, which he presented in different style contexts. The interval of the minor third (minor genus) is here used widely. Rebikov's choice is a representation of style stratification of Slovak folk songs. Rebikov used a colourful piano sound in respect of accompanying function of the piano to the singing voice. His piano adaptations do not use the schematic compositional approach in more music parameters and used a modern harmonic language for the time.

8.3. 38 artistic songs
for voice with piano accompaniment by the Slovak composer Ján Levoslav Bella (1843-1936) represent Slovak classical music. They were created in the same period as the songs by Francisci and Rebikov, but the tunes are originally created by a composer, so they are not folk melodies (see FERKOVÁ 2017b).

8.4. 30 artistic songs
by Franz Schubert (selection according to the availability of MIDI on https://www.classicalarchives.com/) represent European classical music. (For more about Schubert's chord class preferences in his piano pieces, see FERKOVÁ – ŠIDLÍK – ŽDÍMAL 2009 and FERKOVÁ – ŠIDLÍK – ŽDÍMAL 2007).

8.5. 42 songs mostly world famous popular music
by various composers and bands, such as The Beatles, Pink Floyd, Queen, etc. downloaded in MIDI from the internet (more in ADAMOVÁ 2018 and FERKOVÁ – URBANCOVÁ – ADAMOVÁ 2019). Several criteria were applied when selecting the popular songs:
- According to the *type of musical composition* – vocal-instrumental songs typical in classical music and popular music in great numbers.
- According to *style* – selected songs of different styles from jazz to metal.
- According to possible *diffusions of classical and popular music* (in harmony, form, instrumentation, etc.).
- According to the quality and *availability of MIDI files*.

9. APPLICATIONS OF CHORD CLASS ANALYSIS
This chapter presents a comparison of the frequencies of eleven basic classic chord classes and their statistical significance in five sets of songs. These counts were computed as an output of the first phase of the work of the above described original computer software (by co-authors – the musicologist, Eva Ferková, and the computer programmer, Michal Šukola).

The explication of the statistical calculations goes on with finding those results which are statistically relevant and significant. Last but not least, relationships between the type (or genre) of the song-sets are stated, the most frequent chord classes. Song sets are also characterized by the statistically significant frequency of the occurrence of a particular tonal key and/or most frequented cadence cycles.

The *main hypothesis* is that the use of various structures of chord classes, tonal keys and/or cadence cycles is statistically significant to the differentiation of various genre (or style)-homogenous song-sets.

We also assume that the major-tonality of songs is correlated with the highest count of major triads, dominant sevenths and major sevenths, and minor-tonality is correlated with a higher count of minor triads, diminished sevenths, diminished-minor sevenths and minor sevenths.

Differences could be found between sets of different genres, which are according to Czech musicology (see FUKAČ – POLEDŇÁK 1977, p. 316) dichotomic in 'artificial' and 'non-artificial' music, or according to Philip Tagg (TAGG 1982) trichotomic, i.e. (1) art music, (2) popular music, and (3) folk (or national) music.

Harmony is one of the main musical features, according to which it is possible to distinguish the stated music types or music genres.

10. EXAMPLES OF HARMONIC ANALYSIS LAYOUT
10.1. In a Sibelius score
The results of the chord class analysis can be viewed in two forms:

- as symbols of chord classes which occurred in particular beats of the music under the score section of the layout (Figs. 1-4).
- as a count of every chord class which occurred in the analysed composition presented in the tables (Tables 5-10).

The results of the key detection and determination of the harmonic-function for every chord class is possible to see as symbols of the key names (see Figs. 2-4) and as symbols of the functions (Figs. 3-4).

The results of the cadence identification can be seen as demarcated specific strings of harmonic functions in harmonic schema (according to Table 2, Fig. 4)

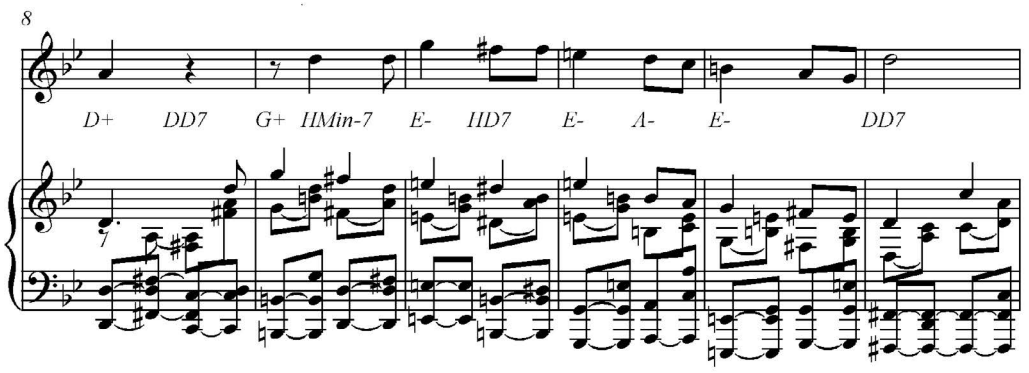

Fig. 1: **Symbols of chord classes under each beat of the score (J. L. Bella: song in G minor, measures 8-13)**

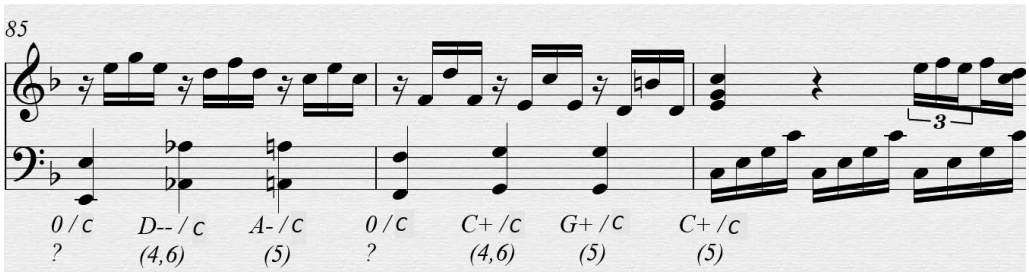

Fig. 2: **Symbols of chord classes in the first line of results and symbols of tonal key in the second line (W. A. Mozart: piano sonata F minor, 1st movement, measures 85-87)**

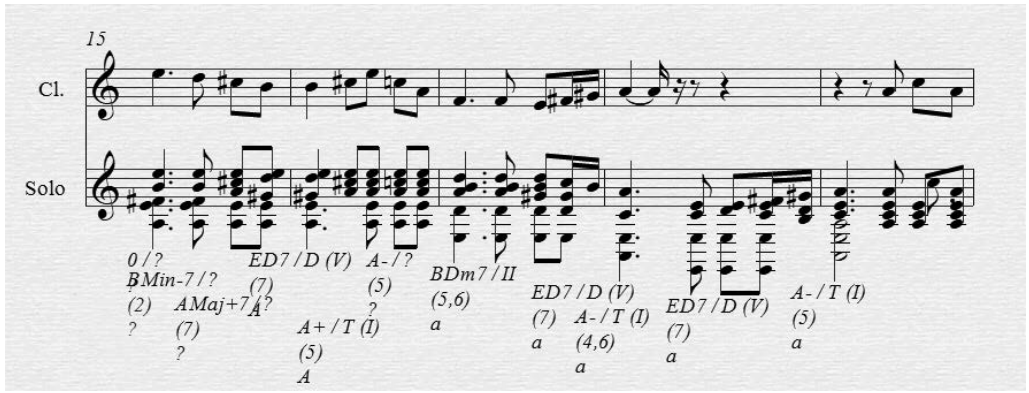

Fig. 3: **F. Schubert: Abendstern song, measures 15-19.**

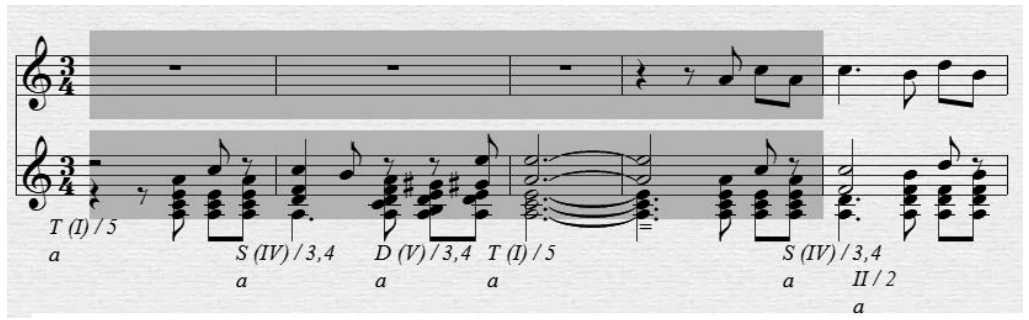

Fig. 4: **F. Schubert: Abendstern song, measures 1-5** (Demarcated string of harmonic functions which was detected as the cadence. Output without visible results of the chord class analysis.)

The results of all three phases of harmonic analysis are visible under the score system of two score lines (where the upper one is for the singer and the lower should be in two score systems, such as a piano accompaniment. The Sibelius layout of this MIDI file is not correct as notation, while the MIDI information was not optimal for score presentation). The first character is the chord name, beginning with the note-name of the root (0 for an unknown chord), the second one is the type of chord class, after '/' is given the name of the harmonic function, in ( ) is given the Roman number of the scale degree, in another ( ) Arabian numbers are given for the inversion of the chord, and the last name is the name of the key.

Numbers for chord inversions are:

- 5 for root position of the triad, 7 for the root position of the seventh chord;
- 6 or 5,6 is the first inversion of the triad or seventh chord;
- 4,6 or 3,4 is the second inversion of the triad or seventh chord;
- 2 is the third inversion of the seventh chord.

10.2. In tables: frequencies of occurrence in statistical results (fractions of complete tables)

Table 5: **Songs by F. Schubert**

File name	Maj5	Min5	Dim5	Augm5	D7	Dim7	Dm7	Maj7	Min7	MinMaj7	Augm7
Abendstern, D. 806.mid	17.0 (17 %)	30.0 (29 %)	0.0 (0 %)	0.0 (0 %)	12.0 (12 %)	6.0 (6 %)	12.0 (12 %)	11.0 (11 %)	10.0 (10 %)	0.0 (0 %)	0.0 (0 %)
Abschied, D. 578.mid	27.0 (18 %)	48.0 (32 %)	0.0 (0 %)	3.0 (2 %)	22.0 (15 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	6.0 (4 %)	0.0 (0 %)	3.0 (2 %)
Adelaide, D. 95.mid	120.0 (45 %)	45.0 (17 %)	8.0 (3 %)	3.0 (1 %)	39.0 (15 %)	4.0 (2 %)	4.0 (2 %)	7.0 (3 %)	5.0 (2 %)	1.0 (0 %)	3.0 (1 %)
An Emma, D. 113, Op. 58, No. 2.mid	55.0 (42 %)	16.0 (12 %)	0.0 (0 %)	1.0 (1 %)	42.0 (32 %)	3.0 (2 %)	2.0 (2 %)	3.0 (2 %)	6.0 (5 %)	0.0 (0 %)	2.0 (2 %)
An die Freude, D. 189.mid	230.0 (50 %)	36.0 (8 %)	12.0 (3 %)	0.0 (0 %)	92.0 (20 %)	0.0 (0 %)	8.0 (2 %)	8.0 (2 %)	12.0 (3 %)	0.0 (0 %)	8.0 (2 %)
Der Fischer, D. 225, Op. 5, No. 3.mid	51.0 (35 %)	4.0 (3 %)	0.0 (0 %)	0.0 (0 %)	48.0 (33 %)	4.0 (3 %)	0.0 (0 %)	12.0 (8 %)	12.0 (8 %)	0.0 (0 %)	0.0 (0 %)

Table 6: **Songs by J. L. Bella**

File name	Maj5	Min5	Dim5	Augm5	D7	Dim7	Dm7	Maj7	Min7	MinMaj7	Augm7
01.MID	22.0 (31 %)	11.0 (16 %)	0.0 (0 %)	0.0 (0 %)	17.0 (24 %)	0.0 (0 %)	2.0 (3 %)	7.0 (10 %)	8.0 (11 %)	1.0 (1 %)	2.0 (3 %)
02.MID	75.5 (41 %)	12.0 (7 %)	1.0 (1 %)	2.0 (1 %)	34.0 (19 %)	14.0 (8 %)	17.0 (9 %)	3.5 (2 %)	23.0 (12 %)	1.0 (1 %)	0.0 (0 %)
05.MID	68.25 (29 %)	45.25 (19 %)	2.25 (1 %)	2.0 (1 %)	41.25 (17 %)	14.5 (6 %)	9.5 (4 %)	9.75 (4 %)	22.5 (10 %)	4.0 (2 %)	2.0 (1 %)
06.MID	39.5 (23 %)	29.375 (17 %)	1.375 (1 %)	1.0 (1 %)	33.875 (20 %)	2.5 (1 %)	4.5 (3 %)	6.25 (4 %)	24.5 (14 %)	1.0 (1 %)	4.5 (3 %)
07.MID	21.5 (28 %)	28.0 (36 %)	1.0 (1 %)	0.0 (0 %)	18.0 (23 %)	0.0 (0 %)	3.0 (4 %)	0.0 (0 %)	4.0 (5 %)	0.0 (0 %)	0.0 (0 %)
10.MID	54.875 (34 %)	40.0 (25 %)	1.0 (1 %)	3.0 (2 %)	14.5 (9 %)	0.0 (0 %)	13.5 (8 %)	8.5 (5 %)	8.125 (5 %)	0.0 (0 %)	2.0 (1 %)

The tables 5 and 6 are comparable, as these songs are original art musical pieces. The world famous, Franz Schubert (1797-1828), who composed in the early nineteenth century, was progressive as regards his harmonic ideas. This is evident in his preferences. In almost every song, he also used seventh chords, including Maj+7 and Min-7. Ján Levoslav Bella (1843-1936), a Slovak composer, who lived nearly half a century later than Schubert, was not much more advanced in his use of different seventh chords. The difference from Schubert is visible in his preferences for very dissonant chord classes, such as Aug7 and MinMaj7.

Table 7: **Slovak folk songs recreated by V. Rebikov**

File name	Maj5	Min5	Dim5	Augm5	D7	Dim7	Dm7	Maj7	Min7	MinMaj7	Augm7
rebikov 1.mid	13.0 (28 %)	18.5 (40 %)	0.0 (0 %)	0.0 (0 %)	4.0 (9 %)	0.0 (0 %)	2.0 (4 %)	0.0 (0 %)	1.0 (2 %)	0.5 (1 %)	0.0 (0 %)
rebikov 11.mid	0.0 (0 %)	29.5 (61 %)	0.0 (0 %)	1.0 (2 %)	0.0 (0 %)	0.0 (0 %)	0.5 (1 %)	1.5 (3 %)	7.0 (15 %)	0.0 (0 %)	0.0 (0 %)
rebikov 13.mid	11.0 (26 %)	3.5 (8 %)	1.0 (2 %)	2.0 (5 %)	3.0 (7 %)	0.0 (0 %)	3.5 (8 %)	1.5 (4 %)	11.5 (27 %)	0.0 (0 %)	0.0 (0 %)
rebikov 14.mid	9.5 (22 %)	12.0 (28 %)	0.0 (0 %)	0.0 (0 %)	5.0 (12 %)	0.0 (0 %)	4.5 (11 %)	1.0 (2 %)	8.5 (20 %)	0.0 (0 %)	0.0 (0 %)
rebikov 15.mid	12.5 (22 %)	0.5 (1 %)	2.0 (4 %)	0.0 (0 %)	10.0 (18 %)	0.0 (0 %)	3.0 (5 %)	4.0 (7 %)	10.0 (18 %)	0.0 (0 %)	0.0 (0 %)

Table 8: **Slovak folk songs adapted by M. Francisci**

	Maj5	Min5	Dim5	Augm5	D7	Dim7	Dm7	Maj7	Min7	MinMaj7	Augm7
01_Pod_tym_ nasim_...mid	27.75 (57 %)	9.0 (18 %)	0.0 (0 %)	0.0 (0 %)	6.0 (12 %)	0.0 (0 %)	2.0 (4 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)
02_Tancuj_tan-cuj_...mid	12.0 (50 %)	5.0 (21 %)	0.0 (0 %)	0.0 (0 %)	6.5 (27 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)
04_Nitra,_nitra. mid	4.5 (23 %)	5.75 (29 %)	0.0 (0 %)	1.5 (8 %)	2.5 (13 %)	0.75 (4 %)	0.75 (4 %)	0.0 (0 %)	0.0 (0 %)	1.25 (6 %)	0.0 (0 %)
05_Tou_nasou... mid	21.0 (47 %)	0.5 (1 %)	0.0 (0 %)	0.0 (0 %)	14.0 (31 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)
07_Este_sa_nevy-dam.mid	8.0 (40 %)	4.0 (20 %)	0.0 (0 %)	0.0 (0 %)	4.0 (20 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)
08_Prajska_zem. mid	13.5 (45 %)	1.0 (3 %)	0.5 (2 %)	0.0 (0 %)	7.25 (24 %)	0.0 (0 %)	1.5 (5 %)	0.0 (0 %)	0.5 (2 %)	0.0 (0 %)	0.0 (0 %)

Harmonized one voice Slovak folk tunes show limitations in the use of a rich variety of chord classes. The musical invention of Miloslav Francisci (more in FERKOVÁ – URBANCOVÁ 2017, or in FERKOVÁ 2017b) depended on his knowledge of classical harmony. There are more harmonized Slovak songs which would limit his ability to use dissonant triads and seventh chords. The results in the table 8 also highlight the musical thinking of the Russian composer, Vladimir Rebikov (not as consonant as Francisci's harmonisations, with more seventh chords). He is considered to be a representative of a new (impressionistic) music from the early twentieth century (see also [10]).

Table 9: **Popular music songs: Files with length of chords in percentages**

File name	Maj5	Min5	Dim5	Aug5	D7	Dim7	Dm7	Maj7	Min7	MinMaj7	Aug7
03 – Bill Danoff, Taffy Nivert and John Denver: Country Roads.mid	21 %	13 %	3 %	0 %	12 %	1 %	1 %	9 %	8 %	1 %	4 %
05 – Bobby Hebb: Sunny.mid	9 %	18 %	0 %	0 %	23 %	1 %	4 %	14 %	19 %	1 %	1 %
09 – Elton John and Tim Rice: Circle of Life.mid	46 %	10 %	0 %	0 %	13 %	0 %	0 %	8 %	14 %	0 %	6 %
10 – Eric Carmen: All by Myself.mid	23 %	10 %	3 %	0 %	15 %	0 %	13 %	0 %	15 %	0 %	1 %
11 – Francesco Sartori and Lucio Quarantotto (Andrea Bocelli): Con te partirò.mid	49 %	13 %	0 %	0 %	5 %	0 %	1 %	8 %	20 %	0 %	0 %
12 – Frank Farian, George Reyam, Fred Jay (Boney M): Rasputin.mid	13 %	16 %	1 %	1 %	18 %	0 %	1 %	8 %	5 %	10 %	3 %
13 – Hoagy Carmichael and Stuart Gorell (Ray Charles): Georgia on My Mind.mid	12 %	5 %	4 %	0 %	21 %	5 %	13 %	5 %	21 %	5 %	4 %
14 – Irving Berlin (Frank Sinatra): Cheek to Cheek.mid	12 %	3 %	0 %	1 %	11 %	8 %	4 %	9 %	33 %	5 %	7 %

Most of the analysed pop songs are in a major key. The most common chord classes (further CC) are major triad (Maj5), then Min5, followed closely by Min7. D7 and Maj7 (also well represented). Popular music authors often use Dm7. Relatively little used are Augm7, Dim5, MinMaj7 and Dim7. A rarely used CC is Augm5. About 10 % of sounds were not recognized as chords, probably where there is one voice sound, or incomplete CCs, thickened CCs, and quart-quint CCs. Five songs were found to contain a combination of major and minor keys.

10.3. In statistics – cross comparison and statistical significance

Table 10: **Some chosen statistical results**

Independent Samples T-Test								
	W	p		W	p		W	p
Maj5	655.0	< .001	Maj5	118.000	< .001	Maj5	6740	< .001
Min5	657.0	< .001	Min5	44.000	< .001	Min5	7425	< .001
Dim5	1907.5	0.913	Dim5	1245.500	0.013	Dim5	5963	< .001
Augm5	1866.0	0.900	Augm5	1314.000	0.003	Augm5	5605	< .001
D7	1307.5	0.033	D7_11	408.000	< .001	D7	6830	< .001
Dim7	2041.0	0.987	Dim7	1552.500	0.292	Dim7	5626	< .001
Dm7	1443.5	0.130	Dm7	501.000	< .001	Dm7	7094	< .001
Maj7	418.5	< .001	Maj7	47.500	< .001	Maj7	7200	< .001
Min7	125.0	< .001	Min7	3.500	< .001	Min7	7682	< .001
MinMaj7	1353.5	0.046	MinMaj7	763.000	< .001	MinMaj7	5944	< .001
Augm7	852.0	< .001	Augm7	334.500	< .001	Augm7	6019	< .001
No	688.5	< .001				No	6619	< .001
Note: Mann-Whitney U test.			Note: Mann-Whitney U test.			Note: Mann-Whitney U test.		
Note: For all tests, the alternative hypothesis specifies that the *classical* group is less than the *popular* (in green).			Note: For all tests, the alternative hypothesis specifies that the *folk* group is less than the *popular* group (in green).			Note: For all tests, the alternative hypothesis specifies that the *classical* group is greater than the *folk* group (in green).		

10.3.1. Explanations of statistical results

When we compared popular songs with songs by Schubert, Bella (classical authors), Rebikov (between classic and folk) and Francisci (folk composer-adapter of folk songs), we found that there is a statistically significant difference in the occurrence of Maj5, Min5, Dim7, Maj7, Min7, Augm7 and unknown chords.

We found that for classical authors there are fewer CCs Maj5, Min5, Maj7, Min7, MinMaj7, Augm7 than in popular songs. Conversely, Dim7 is more used in classical and folk music than in popular music. Further we found that there is a statistically significant difference between all types of CCs, except Dim7, None of the chord classes is more frequent in folk music than in popular music.

Almost every song with a higher occurrence of Min5 than Maj5 is in a minor key. The songs which start with a major key and the Min5 quantity is high, changed/modulated into a minor key.

The majority of the analysed songs are in a major key.

The most frequent chord classes for all song sets are (most frequent first):
- major triad (signed Maj5);
- minor triad (Min5);
- minor seventh (Min7);
- dominant seventh (D7);
- major seventh (Maj7).

Popular music authors also often use the half diminished seventh (Dm7).

Chord classes with an augmented triad inside the chord structure are relatively infrequently used, i.e.:
- augmented seventh (Augm7);
- minor-major seventh (MinMaj7);
- augmented triad (Augm5) – often the least frequently used chord class.

Chord classes without a major/minor triad are also unusual:
- diminished triad (Dim5);
- diminished seventh (Dim7).

About 10 % of sounds were not recognized as chord classes, so we can assume that they are incomplete chords, non-chords, or sounds with a different inner structure than a third (i.e. quart-quint, etc.)

Five songs were found to contain a combination of a major and minor key. The best example is the song, Delilah, which has almost the same number of a major triad (Maj5) as a minor triad (Min5), as the verses are in a minor key and the chorus in the major key. We also found

that when a pop song has major and minor chords, the key is not necessarily the same. The song can have many major chords, while being in a minor key. In the statistical comparison of pop / rock and jazz styles, we found that augmented triad, dominant seventh, diminished seventh and minor-major seventh (Augm5, D7, Dim7 and MinMaj7) are more commonly used in jazz.

In the comparison of popular and classical songs (by Bella and Schubert and some by Rebikov), we found there is a statistically significant difference in the occurrence of:
– major triads Maj5 (more frequently used in popular songs);
– minor triads Min5 (more frequently used in popular songs);
– diminished seventh Dim7 (more frequently used in classical music);
– major seventh Maj7 (more frequently used in popular songs);
– minor seventh Min7 (more frequently used in popular songs);
– augmented seventh Augm7 (more frequently used in popular songs);
– unknown sounds;
– minor major seventh MinMaj7 (less frequent in songs by classical authors).

When we compared the occurrence of each chord class in classical, popular and folk songs, we found there is a statistically significant difference in occurrence of all chord classes and they are more frequent in classical and popular than in folk music (except diminished seventh – Dim7 – which is more frequent in classical and folk music).

11. CONCLUSION

The fact that none of the chord classes is more frequent in folk songs than in classical or popular music songs suggests that the dichotomy between 'artificial' and 'non-artificial' music is not correct if 'non-artificial' music is considered to include both folk and popular music.

The high frequency of varied chord classes shows the harmonic similarity between classical and popular music and the contrast with (adapted) folk music. Therefore, we propose a new genre/type classification with a dichotomy between:
– composed music (or individual music including classical and popular music);
– folk music (with unknown author – collective music or traditional music).

The trichotomy, suggested by Philip Tagg (TAGG 1982) – i.e. (1) art music, (2) popular music, (3) folk music – is also acceptable, as the stated differences in most chord classes between classical and popular songs.

In further research, based on applications of the Harmanalysis software, we intend to apply it to the statistical calculation of cross-comparisons of the usage of various keys in connection with various cadence formulas (or cadence cycles) and also in correlations with other features and/or with style of the composer or music genre.

References

ADAMOVÁ, Silvia (2018): 'Difúzie klasickej a populárnej hudby vo vybraných dielach raného 20. storočia', *Musicologica Slovaca* 9 [35] (2018), pp. 238-290.

FERKOVÁ, Eva (2017a): 'Computer Analysis and Visualisation in the Music Theory Research', *Clavibus unitis* 6 (2017), http://www.acecs.cz/media/cu_2017_06_ferkova.pdf.

FERKOVÁ, Eva (2017b): 'Harmonické preferencie ako štýlový znak skladateľskej poetiky. Príspevok k charakteristike úprav ľudových piesní pre klavír Miloslava Francisciho', *Musicologica Slovaca* 8 [34] 2017, pp. 169-187.

FERKOVÁ, Eva – KAČIC, Ladislav 2018: *Music Theory in the Past and Today. Three Approaches* (Bratislava: Vysoká škola múzických umení, 2018).

FERKOVÁ, Eva – ŠIDLÍK, Peter – ŽDÍMAL, Milan (2007): 'Chordal Evaluation in MIDI-Based Harmonic Analysis: Mozart, Schubert, and Brahms', in: *Tonal Theory for the Digital Age* [= Computing in Musicology 15 (2007)], pp. 172-186, http://www.ccarh.org/publications/books/cm/vol/15/cm15-09-ferkova.pdf.

FERKOVÁ, Eva – ŠIDLÍK, Peter – ŽDÍMAL, Milan (2009): 'Computer-Aided Investigation of Chord Vocabularies: Statistical Fingerprints of Mozart and Schubert', in: *Mathematics and Computation in Music* [= Communications in Computer and Information Science, 37] (Berlin – Heidelberg: Springer, 2009), pp. 250-256, https://books.google.sk/books?id=UUJuCQAAQBAJ&pg=PA250&lpg=PA250&dq=ferkov%C3%A1+Eva+investigation&source=bl&ots=gxLzWM7VPL&sig=ACfU3U3hqXU1AYPOLBUeEUnn4n6_o-HQgg&hl=sk&sa=X&ved=2ahUKEwjgoqO518XsAhXioXEKHakmDBIQ6AEwEnoECAEQAg#v=onepage&q=ferkov%C3%A1%20Eva%20investigation&f=false

FERKOVÁ, Eva – URBANCOVÁ, Hana (2017): 'Adaptations of Slovak Folk Songs for Piano in the Context of (Ethno)Musicological Analysis', in: *FMA 2017. Proceedings of the 7th International Workshop on Folk Music Analysis, 14-16 June 2017, Málaga, Spain* (Málaga: Universidad Málaga de Málaga, 2017), http://fma2017.uma.es/docs/FMA2017_proceedings.pdf, pp. 128-129.

FERKOVÁ, Eva – URBANCOVÁ, Hana – ADAMOVÁ, Silvia (2019): 'Usage Rate of Chords and Keys as Basis for Genre Comparison and Differentiation', in: *16th International Conference on Music Analysis and Theory, 10-13 October 2019, Rimini, Italy (Dichotomous Paths and Clashes: Complexities and Multiplicities in Music Analysis and Theory)* (Rome: Universitalia, 2019), pp. 45-46.

FILIP, Miroslav (1997): *Súborné dielo*, I: *Vývinové zákonitosti klasickej harmónie* (Bratislava: Národné hudobné centrum, 1997).

FORTE, Allen (1973): *The Structure of Atonal Music* (New Haven: Yale University Press, 1973).

FUKAČ, Jiří – POLEDŇÁK, Ivan (1977): 'K typologickým polarizacím hudby, zejména polarizaci hudby artificiální a nonartificiální', *Hudební věda* 14 (1977), https://kramerius.lib.cas.cz/uuid/uuid:1e99eab0-bd01-430c-8f14-42fe7a78ed17, pp. 316-335.

GRICH, Stanislav (2013): *Muzikológia a digitálna technika z pohľadu súčasnosti*, Ph.D. diss. (Brno: Masarykova univerzita, Filozofická fakulta, 2013), https://is.muni.cz/th/obqni/.

PISTON, Walter (1987): *Harmony*, the 5th ed. (New York – London: Norton, 1987).

RANDEL, Don Michael (ed.) (1978): *The Harvard Concise Dictionary of Music and Musicians* (Cambridge, MA: The Belknap Press, 1978).

ROSNER, Burton S. – NARMOUR, Eugen (1992): 'Harmonic Closure: Music Theory and Perception', *Music Perception* 9/4 (1992), pp. 383-412.

TAGG, Philip (1982): 'Analysing Popular Music: Theory, Method and Practice', *Popular Music* 2 (1982), pp. 37-65; for revised version see https://tagg.org/articles/xpdfs/pm2anal.pdf.

TYMOCZKO, Dmitri (2010): 'Music 105', Handout 14 (2010), https://moam.info/music-105-handouts-dmitri-tymoczko_59d52fbf1723dd9537184e27.html.

