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A Comparative Analysis of Eurasian Folksong Corpora, using Self Organising Maps

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Background in artificial intelligence research. The idea of analysis of large folksong corpora using mathematical tools and computer goes back to the 60's, but the intensive research started in the 90's, when a large scale of self-learning algorithms has been applied in music research. The application of artificial intelligence research and data mining in musicology allows us to discover hidden regularities of music and understand certain functions of human cognition.
Background in ethnomusicology. To study interethnic and historical relations, Bartók and Kodály compared different layers of Hungarian folk music to those of other nations living in the neighborhood of Hungarians. Later, they extended the study on Anatolian, Mari and Chuvash folk music. The fascinating results of these latter comparisons lead to the conclusion that folk music can preserve very old common musical structures, and may refer to early cultural contacts.
Aims. We report on a comparative analysis of 16 folksong corpora representing different folk music traditions in Eurasia. Our aim is to reveal some hidden musical relations between different cultures and areas of the continent.
Main contribution. We applied self organizing mapping for automatic classification of melody contours of 16 European and Asian folksong corpora. We characterized the strength of the contacts between musical cultures by a probability density function. We show that the relationships identify an "Eastern" and a "Western" sub-system that are associated due to the close relations between the Finnish and Irish-Scottish-English musical cultures to the Carpathian Basin. We also show that "Eastern" cultures define a very clear overlap of melody types, functioning as a common crystallization point of musical evolution.
Implications. The results show that computer-aided music analysis can reveal a complete system of cross-cultural relations, and may detect early historical contacts.

Keywords: Comparative musicology, neural networks, ethnomusicology, artificial intelligence research, data mining.

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Introduction

A cross-cultural comparison of folk song structures may lead to significant conclusions concerning the evolution of the music and cultural interactions in wide historical periods. For instance, Kodály identified a very archaic layer in Hungarian folk music by finding common fifth shifting structure and pentatonic scale in a convincing amount of Hungarian as well as Mari and Chuvash melodies. This result, firstly published in 1937, also revealed the surprising historical endurance of oral musical cultures, since living cultural contacts between Hungarian, Mari and Chuvash people date back to the 5^{th}-6^{th} centuries (Kodály, 1971). The idea of a more systematic, computer-aided comparative study arises in the 50's (Freeman and Merriam, 1956). Kodály initiated a project to develop a representative digitized European folksong database and a program system for its comparative analysis in the early 60's (Csébfalvy & al., 1965) .

Current research, based on interdisciplinary cooperation of musicology, artificial intelligence research and data mining, focuses on automatic measurement of similarity, segmentation, contour analysis and classification using different statistical characteristics, e.g. pitch interval distribution or rhythm distribution. A very widely used kind of artificial neural networks (Kohonen, 1995), the so-called self organising map (SOM) was used for classification of certain musical statistics of Finnish folk music (Toiviainen, 1996; Toiviainen, 2000; Krumhansl & al, 1999, Krumhansl & al, 1999), as well as the musical timbre (De Poli, Prandoni, 1996). Self organising maps have also been applied in a complex model of human music cognition (Leman, 2000). Large folksong corpora of the Essen collection were classified by determining typical contour averages (Huron, 1996). A systematic description of Hungarian folk music in a multidimensional space was based also on the study of melody contour, using principal component analysis (Juhász, 2002).

The measurement of melodic similarity is a crucial problem of computer aided folksong research, music retrieval and music cognition analysis. A wide scale of methods has been published in the field of melody similarity measurement, focusing on the pitch or on the rhythm (Volk et al.,2007, Antonopoulos & al. 2007, Chordia, 2007), applying string edit distance (Orpen, Huron, 1992), earth mover's distance algorithm ((Schmuckler, 1999; Garbens et al., 2007), spectrum analysis of a graph representing conditions of consecutive notes in a melody (Pinto et al.,2007), measuring the distance of the contour by Euclidean distance (Juhász, 2006), or dynamic time warping (Juhász, 2007). A complex SOM-based system has been elaborated for simultaneous analysis of the contour as well as the pitch, interval and duration distributions (Toiviainen, Eerola, 2002). A SOM-based system has been elaborated for simultaneous analysis of the contour as well as the pitch, interval and duration distributions (Toiviainen, Eerola, 2001; Toiviainen, Eerola, 2002). The problem of an adequate data representation and search strategy for music has also been discussed in general (Selfridge-Field, 1998; Schmuckler, 1999; Müllensiefen, 2007).

The comparative study described in the present article is based on the analysis of the melody contour, applying a weighted version of the Euclidean distance as a similarity measure. In order to describe and compare the musical systems of the studied 16 Eurasian cultures, the self learning feature of the SOM has been utilized to determine the most characteristic contour types. The applicability of this technique has been verified in a previous work analysing the relationships in 6 European folksong corpora (Juhász, 2006).

Melody corpora

The melody collections to be analyzed originate partly from written sources digitized by ourselves, and partly from digital databases, e.g. the Essen Collection, the Finnish Folksong Database, the "Old Hungarian Folksong Types" collection, free melody collections published in ABC code on the internet and more extensive databases arising from the above mentioned early Hungarian project in the 60ths. The Luxembourgian-Lotharingian and the Polish collections are personal donations of Ewa Dahlig-Turek (Polish Academy of Sciences) and Damien Sagrillo (University of Luxembourg). The sources and sizes of our databases are summarized in the table below.

Table 1. The sources and sizes of the databases.

Database Source	# of pieces
Hungarian: (Dobszay, Szendrei 1992)	2323
Slovak: (Slovenské Ludové Piesne, 1950)	1940
French: (Canteloube, 1951; D'Harcourt 1956, ABC)	2048
Sicilian: (Favara, 1957)	1380
Scotish-Irish-English: (Sharp, 1932; Bruce & Stokoe, 1882, Bacon)	2207
Bulgarian: (Stoin, 1931)	1040
German: (ESAC: Erk, Boehme)	2421
Volga-region: (Vikár-Berczki, 1971-1999)	1604
Chinese: (ESAC)	2041
Mongolian (Monγol, 1981)	1568
Karachay: (Sipos, Agócs field rec)	1099
Anatolian Turkish: (Sipos J,1994)	2299
Finnish: (Eerola, 2004)	2400
Luxemburgian+Lotharingian: D. Sagrillo	1200
Polish (Cassubian): E. Dahlig Turek	1572
Spanish: (Garcia; MTA, 2000; ABC)	1418

Since all of the above corpora have been assembled and notated by experts, we consider them as representative samples of 16 Eurasian national or areal musical cultures. The meaning of the expression "representation" is not the same for all the databases. For instance, the "Polish" corpus represents the music of one given ethnic group of a well defined area (Cassubian), while the “Volga” collection contains folksongs of four nations living together in a large geographic region (Mari, Chuvash, Tatar, Votiac). Therefore, in case of necessity, the peculiarity of a given database will be emphasized adding the “national/areal” attribute.

All of the corpora were transcribed in the European system, thus, microtonic and oligotonic phenomena have been filtered by the authors themselves. The phrase structures of the digitized melodies were also taken from the original publications. The only standardization, done by our program automatically, was the transposition of all melodies to the common final tone G.

Methods

As we have mentioned above, our aim was to reveal a comprehensive system of relationships among 16 musical cultures in Eurasia. However, the numerical characterisation of the overall similarity between two folksong corpora is not a simple task. Suppose that we can create a whole collection of melody contour types, containing all the significant contours that appear in any of the 16 cultures. It is obvious that the national/areal sets of contour types can be considered as different subsets of this great common collection, therefore the study of musical connection between different cultures can be determined by the analysis of the intersections of these subsets.

Being in possession of the size of the great common contour type collection (*N*), the sizes of its two national/areal subsets (*A* and *B*), as well as the size of their intersection (*X*), the measure of the relationship between these cultures can be expressed by a probability as follows.

As a first step we compute the probability of the event that a random choice of two subsets with sizes *A* and *B* from the set of size *N* results in an intersection of size *x,* as

$$p(x) = \binom{N}{x} \frac{\binom{N-x}{A-x}\binom{N-A}{B-x}}{\binom{N}{A}\binom{N}{B}}. \tag{1}$$

Using this probability density function, the probability of the event, that the size of the intersection is less than *X*, is expressed as

$$P(X) = \sum_{x=1}^{X-1} p(x). \tag{2}$$

A high value of this probability ($P(X) \approx 1$) indicates that the number of common melody types in the two corpora is much higher than the expected value in case of random correlations. Consequently the similarity, manifested by such high intersection of two corpora, cannot be a product of occasional coincidences of independent musical evolutions. It can be stated in such cases of similarity that the common musical characteristics implicate a historical or present, immediate or intermediate cultural interaction, that is, the established relationship is necessarily deterministic.

To construct the above mentioned sets, firstly we had to deduce the characteristic contour type collections for the 16 corpora one by one, training 16 SOM-s separately. The operation of a SOM is demonstrated in Figure 1. The first step is to construct melody contour vectors of D dimensions (D element pitch sequences) from the digital codes of the music notations. The technique has been described in previous papers, here we summarize it as follows (Juhász, 2002): The pitch was characterised by integer numbers, increasing 1 step by one semitone, while the rhythm was encoded into the duration of the temporal intervals of the pitch-time function determined by the rhythmic value of the corresponding note. For sampling, the total length of the pitch-time function was divided into D portions. Then, the pitch sequence, or in other words the D dimensional "melody contour vector",

$$\underline{x}_k = [x_{1,k}, x_{2,k} \ldots x_{D,k}]^T \quad (3)$$

was constructed from the D consecutive pitch samples of the kth melody, where T denotes the matrix transposition (See the contour vectors in Figure 1).

Since D was the same for each melody, the contours could be compared to each other using a distance function defined in the same D-dimensional melody space, irrespective of their individual length. We found that the choice of $D = 64$ resulted in an appropriate accuracy. The SOM-s were trained by these 64 dimensional melody contour vectors. During the training process, the most characteristic groups of similar melodies were identified and averaged automatically, resulting in types of the contour vectors, as it is shown in Figure 1.

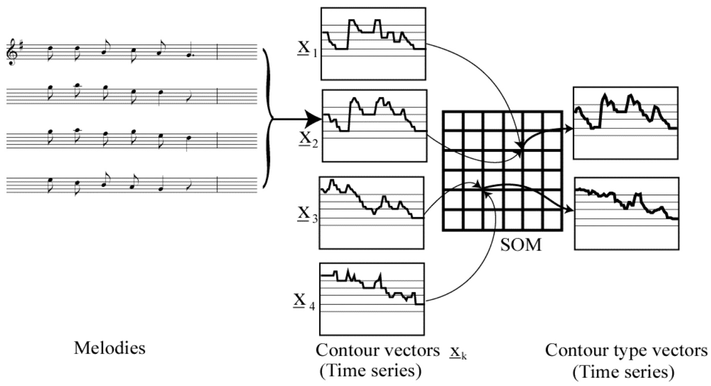

Figure 1. The operation of the self organizing map.

A crucial element of self organising mapping is a distance function measuring the similarity between the individual melody vectors and the contour type vectors defined above and assigned to the lattice points of the map. This musical similarity was defined as a weighted version of the Euclidean distance:

$$\Delta_{i,j} = \sqrt{\underline{d}_{i,j}^{T} \underline{S}_{i,j} \underline{d}_{i,j}} \ , \qquad (4)$$

where $d_{i,j} = c_{i,j} - x_k$ is the difference vector of the contour type vector assigned to location (*i, j*) and the "melody vector" representing a given melody contour. The *DxD* diagonal matrix $S_{i,j}$ contains adaptively learned weights belonging to the vector elements of $c_{i,j}$. The weights are proportional to the pitch stability of the contour type at the corresponding sampling period, that is, stable and variable periods can be distinguished during the analysis (Juhász, 2006).

Results

Using the above technique, we trained 16 SOM-s with the national/areal databases. The map sizes were increased until the percentage of the classified melodies exceeded 80% and remained below 90%. This way the size of the square maps was fitted to the requirements of the databases one by one. The resulting map sizes ranged between 20*20 and 24*24.

After determining the 16 national/areal contour type collections, a new large self organizing map of size 40*40 was trained by the united set of them, in order to determine the set of all possible contour types appearing anywhere in the 16 cultures.

After training a SOM with a database, the resulting contour type vectors can be used to classify the melodies. This classification means that the melody is assigned to one of the contour type vectors of the map with minimal distance between them according to Equation 4, providing that this distance is less than a prescribed critical value. In the opposite case, the melody is said to be not classifiable. The process of classifying all of the melodies belonging to a given corpus (A) on a self organising map, is called "excitation of the map by the corpus A". Accordingly the statement: "the lattice point (i, j) is excited by corpus A" means that at least one melody of A hits the lattice point (i, j), independently of the total number of hits at this location. The national/areal excitations of the map can be visualized by marking the lattice points hit by the exciting contour type vectors. Figure 2 shows the activated area of the great common map after excitation by different national/areal corpora of contour types. It is easy to see that Anatolian, Hungarian and Chinese excitations have a significant common part, while Chinese and German excitations activate nearly detached areas. It follows from the training rule of the SOM that similar melody contours occupy closely located lattice points of the map, that is, such patterns represent topographic mappings of the musical cultures (Kohonen, 1995; Juhász, 2007).

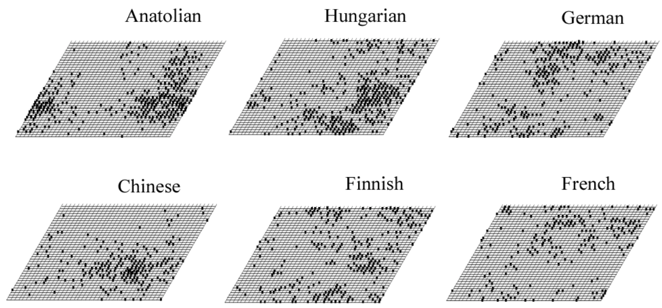

Figure 2. The excitation of the great common map by 6 different national/areal contour type collections.

The values *A, B* and *X* can be determined for any selected two cultures by counting up the lattice points excited in the great common SOM. With these quantities, the calculation of the probability $P(X)$ can be carried out using Equations 1 and 2, knowing that N is equal to the total number of the common contour types. It is worth mentioning here that this calculation avoids the problems arising from the different sizes of the corpora (and the national/areal map sizes), since the expected intersection decreases with decreasing subset sizes A and B.

The graph of the system of closest relationships is summarized in Figure 3., where a connection line indicates a high probability ($0.999 < P(X)$) of deterministic contact between the nodes of musical cultures. The Figure shows two sub-graphs containing an "Eastern" - Chinese, Mongolian, Volga, Karachay-Balkar, Anatolian, Sicilian, Hungarian and Slovak, - as well as a "Western" - Finnish, Irish-Scottish-English, French, German, Luxembourgish and Polish – group of nodes. These two main groups form so called whole sub-graphs, since any couples of them are connected. There is an interconnection between these two large sets due to the presence of a third whole sub-graph of the Hungarian, Slovak, Finnish and Irish-Scottish-English corpora. The Finnish corpus has got some additional affinities to several further

Eastern cultures. Anyhow, the connection of the two main subsystems, based on the contacts between the Hungarian, Slovak, Finnish and Irish-Scottish-English nodes, indicates a special role of these cultures inside their main groups and also in the whole system. Although the contacts of the Bulgarian corpus are not close enough to connect it to the whole system of Eastern cultures, it is very closely related to the Anatolian culture which is classified as Eastern. Since the incomplete connections of the Spanish corpus point to both Eastern (Hungarian and Slovak) and Western (Finnish) nodes, it can not be definitely classified as a member of Eastern or Western culture.

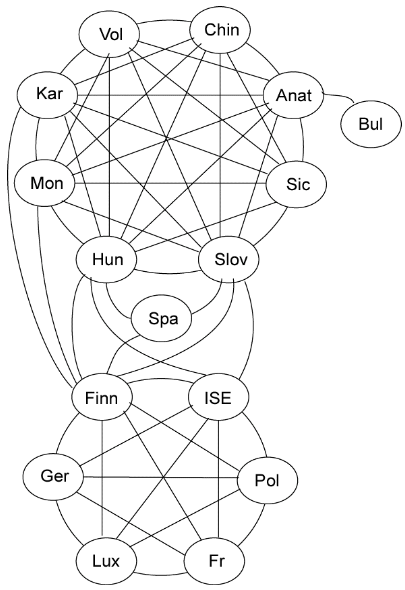

Figure 3. Deterministic contacts of 16 Eurasian folksong corpora. The threshold probability of non-random overlaps is 0.999.

The common melody forms found in selected pairs of corpora can be very variable and depend on the concrete cultures. However, an important question arises: are there major or minor groups of common contour types which exist in parallel in many different cultures? Furthermore, which groups of the 16 cultures have the largest subsets of common melody contour types? An answer to these questions can reveal possible common crystallization points of musical cultures, providing that such groups of common types do exist at all. In order to discover such groups of corpora and contour types in parallel, we developed an algorithm with the aim to find the largest subsets of corpora having the largest amount of common melody types. This aim formulates a search for optimum, since the largest intersections are expected necessarily for the smallest subsets of corpora. In the first step, the algorithm determines all couples of corpora having more common contour types than a threshold value. After that, it adds one further corpus to each couple according to the requirement that the addition of the new corpus must be limited to produce the smallest reduction of the intersection size. This extension of the corpora is repeated until the intersection size reaches a prescribed threshold minimum.

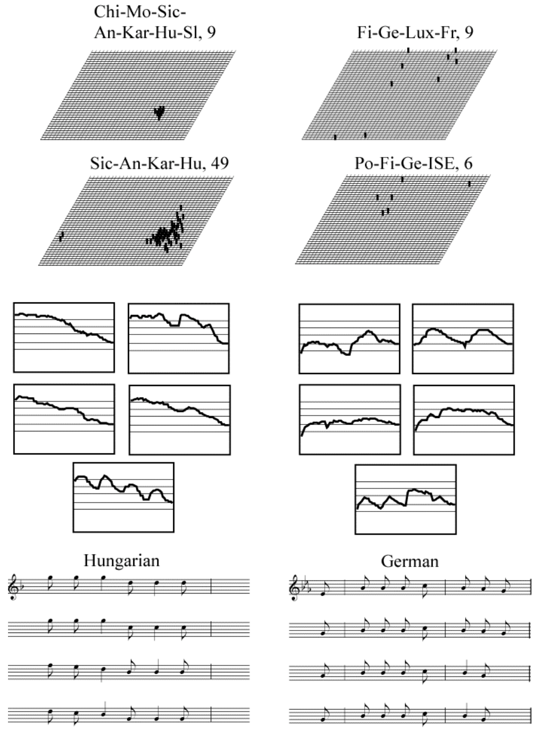

Figure 4. Intersections of 7, as well as 4 national/areal cultures on the great common map. Some characteristic contour type vectors and melody examples are also indicated.

This research led to a set of seven - Chinese, Mongolian, Sicilian, Karachay-Balkar, Anatolian, Hungarian and Slovak - corpora with an intersection of 9 contour types. Searching for the largest intersections in six, five and four corpora, a cohesive extension of the overlap region of the above 9 contour types was found belonging to different subsets of the 7-element culture set, as shown in Figure 4. The types form an interconnected area of the great common map, therefore they construct a cohesive musical "style" of more or less similar types. The melodies of this style are mainly constructed by 4 sections of descending structure and their range is rather large of one octave or more. In some cases, the second halves of the melody types are transposed variants of the first ones downwards by a fifth. (See contour type and melody examples 5 in Figure 5.) Although this style is rather unitary, it can be subdivided into 9 sub-styles according to the ending notes of sections. The melodies in Figure 5 demonstrate characteristic examples for these 9 sub-styles. The corresponding 9 sequences of the section ending notes of the first, second, and third sections are [G(A) - D - C(B,D)], [G (F) - C- C(B)], [G - E - C(B)], [F - D - C(B)], [F - D -

G,/A], [F - C - C], [F - B - B(C)], [D - D - C(B/A)] and [D - C - C(B)], respectively. For instance, in the first sub-style example, the 3 section ending notes are G (sometimes A), D and C (sometimes B or D) and the fourth is definitely G (see Chapter 2.).

Any of this 9 sub-styles of the "Eastern" group can be illustrated by a series of corresponding parallel melodies. The close relationship is emphasized by Figure 6 showing some melody examples belonging to the group [G(A) - D - C(B,D)]. These melodies were taken from different cultures still they provide an impression as if they were variants of one "common" song.

These results indicate a well defined common style residing in all the 7 cultures classified above as members of the "Eastern" group (Figure 4.). One can hardly imagine a different explanation for such common musical style than the existence of a common "parent language" as an initial crystallization point of more or less independent musical evolutions. Earlier studies of the contacts of Hungarian folk music have drawn the conclusion that descending, sometimes fifth transposing melodies of high ambit constitute the most important part of the contact melodies between Hungarian as well as Mari, Chuvash (Kodály, 1971), Anatolian (Bartók, 1949; Sipos, 2000,2006) and Mongolian (Sipos,1997) folk music. Our results show that the coincidences found by these independent studies were not occasional, since they can be deduced from the existence of the common core of the "Eastern" cultures.

Among the Western cultures, the largest class of more or less significant overlap consists of 4 – Finnish, German, Luxembourgish and French – corpora with 9 common contour types, in contrast to the maximum Eastern value of 49 in case of the quartet of the Karachay-Balkar, Anatolian, Sicilian and Hungarian cultures. The 9 Western types are scattered over in the common map, meaning that these melody forms are fairly different, and can not compile a consistent musical style. The corresponding contour type vectors show plagal or authentic melodies with a low ambit. The second largest intersection of the Western corpora belongs to the Polish, German, Luxembourgian-Lotharingian and Irish-Scottish-English cultures. Alhough these contour types are also of narrow range, no common type of the above two Western subsets has been found. These results show the lack of a common musical core in the Western group, not excluding close contacts between any pair of the cultures.

It is worth mentioning here that there are several quartets of mixed Western and Eastern corpora which have significantly larger overlaps than those found in the Western group: (Anatolian, Karachay-Balkar, Hungarian, Finnish), (Sicilian, Karachay-Balkar, Hungarian, Finnish) and (Anatolian, Karachay-Balkar, Hungarian, Spanish). The common contour types of these subsets are further cohesive extensions of the Eastern core, with descending melodies of wide range. This shows that the Finnish and Spanish corpora also contain significant fragments of the Eastern core. Moreover, descending melodies of a wide range can also be found in other Western corpora, but the fragmentary state of this style leads necessarily to small overlaps.

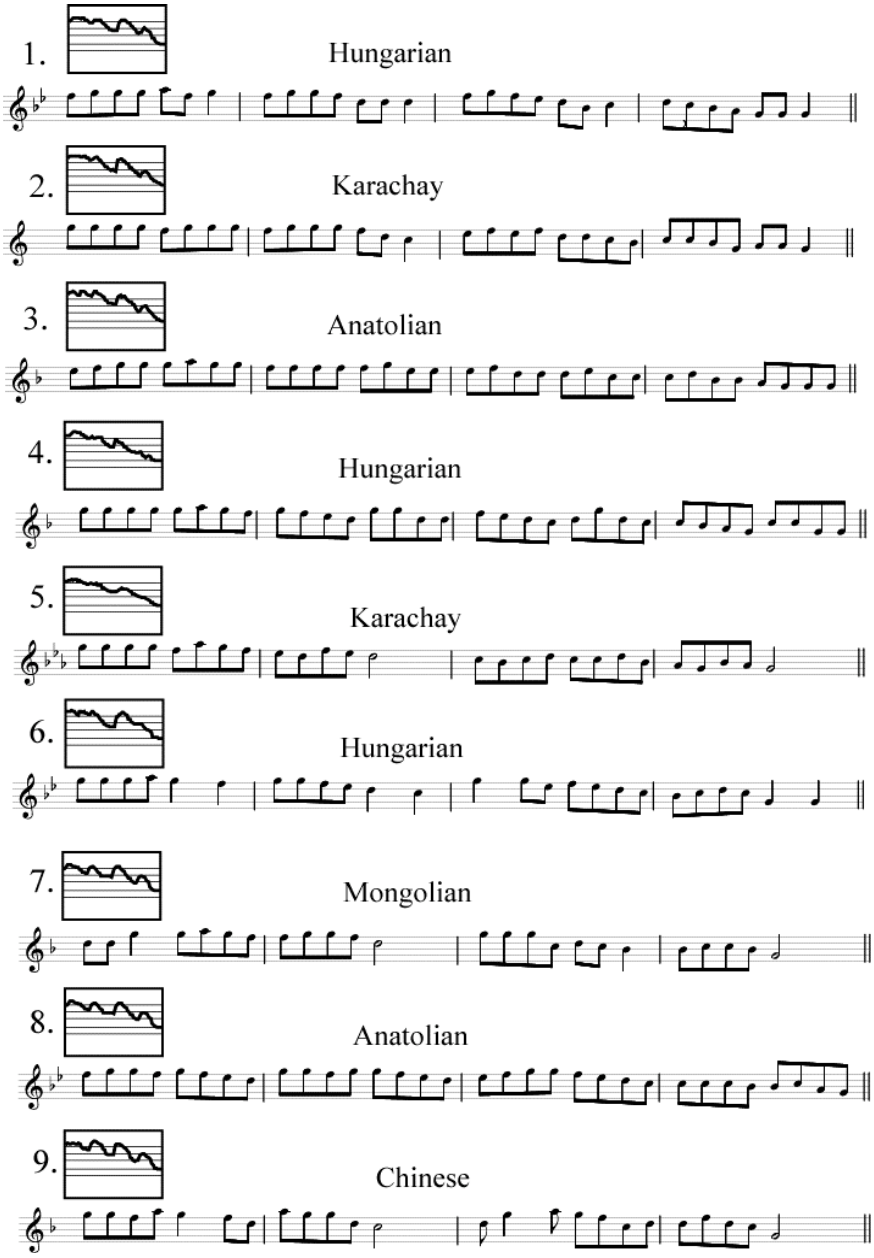

Figure 5. Melody examples characterizing the musical style of the "Eastern core". The corresponding contour type vectors are also indicated.

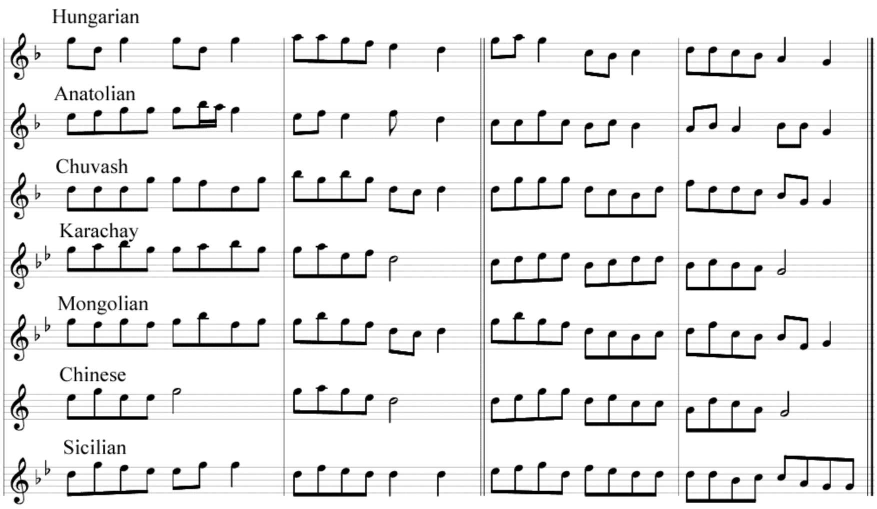

Figure 6. Melody examples belonging to one of the contour types of the “Eastern core”.

Conclusions

We analyzed the overlaps of 16 national/areal melody contour corpora by two different ways. Firstly, we determined the probabilities of the deterministic contacts between couples of corpora, and secondly, we looked for the highest possible overlaps of melody contour types between the largest possible group of corpora. The contour types were determined using self organizing mapping.

Both methods lead to the conclusion that the overwhelming majority of the 16 corpora can be divided into two main parts called here Eastern and Western subsets. The probability analysis showed that these two subsets are connected solely due to the close contacts of the Finnish, Irish-Scottish-English and Spanish cultures to that of the Carpathian Basin (Hungarian and Slovak). The quest for the subsets of corpora with the highest overlap revealed a well defined musical style being the common core of the Eastern cultures, while the same analysis lead to the consequence that the Western musical cultures do not include such a common crystallized melody form. The absence of the common core in the Western music highlights the significance of the Eastern core-style, because it demonstrates that such common melody styles do not necessarily exist even in interactive cultures.

The musical forms of the Eastern core interpret the earlier ethno-musicological findings of Kodály, Bartók and Sipos, who indicated that the high ambit, descending (frequently fifth transposing) melody types are the most characteristic contact melodies between Hungarian and Mari-Chuvash, Anatolian Turkish, as well as Mongolian folk music. We have shown here that this style is a general and important component of any of the studied Eastern musical cultures, but it also exists in certain

Western corpora in a more or less fragmentary state, joining the West to the East with the contribution of the Carpathian Basin.

Our technique focusing on the contour is less sensitive to other important musical characteristics, such as rhythm, mode, or harmonic background. However, some results of the ethnomusicology show that such analysis can well distinguish between relevant classes of melody contours containing different rhythmic and modal variants (Huron, 1996; Dobszay, Szendrei, 1992; Corpus Musicae Popularis Hungaricae 1951-1997).

Independently of this study, self organizing mapping could be applied for the analysis of any other musical characteristics which can be quantitatively formulated as multidimensional vectors. For instance, it could easily be extended to the cantometric coding method of A. Lomax who firstly suggested a global and quantitative comparison of very distant folksong cultures (Lomax, 1964).

Not forgetting the simplifications made during the application of our technique, we can state that the contour analysis allowed us to draw a rather perspicuous picture of the cross-cultural connections of different folksong cultures. We hope that these results may demonstrate the feasibility of an extended research of "musical linguistics", and suggest an efficient and quantitative tool for "melody mining", using artificial intelligences and other mathematical tools.

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Biographies

Zoltán Juhász was born in Budapest in 9. 3. 1955. He graduated at the Faculty of Electrical Engineering of the Technical University in Budapest in 1978. He obtained the "Doctor univ." degree in 1982, as a doctorand of the Central Research Institute of The Hungarian Academy of Sciences, in the field of single crystal growth. After that, he started to work in the field of adaptive learning systems, to elaborate a noise reduction system of early ethnomusical phonograph recordings, as well as an adaptive control system for crystal growth equipments. He obtained the Ph.D. degree in 1997 for this work. His current field of research is computer-aided study of folk music, including interethnic connections. At present, he is the senior research fellow of the Research Institute for Technical Physics and Materials Science, in Budapest. He collects, studies and plays traditional flute and bagpipe music since 1977. Based on his collection, he wrote 3 school-books for traditional flute playing of different Hungarian musical dialects, and two books about the last bagpipe and flute player herds of the Palóc (North-Hungarian) ethnic group. He teaches traditional flute and bagpipe playing at the Liszt Ferenc University of Musical Arts and at the School for Folk Music.

Dr. János Sipos is the senior researcher of the Institute for Musicology of Hungarian Academy of Sciences and the professor of the Franz Liszt Music Academy, Budapest. He graduated at the Faculty of Mathematics of the Attila József University Szeged. From 1987, he has spent all together eight years in areas inhabited by different Turkic people and collected more then 7000 songs in Anatolia, Thrace, Kazakhstan, Azerbaijan, Kyrgyzstan, among Karachays in the Caucasus, Karachays in Turkey and among Navajo and Dakota Indians. Since than, his centre of interest is the comparative analysis of the folk music of Turkic people. He obtained the Ph.D. degree for the dissertation "Béla Bartók's Anatolian Research in the Light of a Larger Material" in 1997. Based on his field work he has published eight books.