A Method for Structural Analysis of Ottoman-Turkish Makam Music Scores

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A METHOD FOR STRUCTURAL ANALYSIS OF OTTOMAN-TURKISH MAKAM MUSIC SCORES

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ABSTRACT

From a computational perspective, structural analysis of Ottoman-Turkish makam music (OTMM) is a research topic that has not been addressed thoroughly. In this paper we propose a method, which processes machine-readable music scores of OTMM to extract and semiotically describe the melodic and lyrical organization of the music piece automatically using basic string similarity and graph analysis techniques. The proposed method is used to identify around 50000 phrases in 1300 music scores and 21500 sections in 1770 scores, respectively. The obtained information may be useful for relevant research in music education and musicology, and it has already been used to aid several computational tasks such as music score content validation, digital music engraving and audio-score alignment.

1. INTRODUCTION

In analyzing a music piece, scores provide an easily accessible symbolic description of many relevant musical components. Moreover they typically include editorial annotations such as the nominal tempo, the rhythmic changes and structural markings. These aspects render the music score a practical source to extract and analyze the melodic, rhythmic and structural properties of the studied music.

Analyzing the structure of a music piece is integral in understanding how the musical events progress along with their functionality within the piece. Automatic extraction of the melodic and lyrical structures, as well as their roles within the composition, might be used to facilitate and enhance tasks such as digital music engraving, automatic form identification and analysis, audio-score and audio-lyrics alignment, music prediction and generation.

Structural analysis is a complex problem which can be approached in different granularities such as sections, phrases and motifs (Pearce et al., 2010). To find such groupings there has been many approaches based on music theory (Jackendoff, 1985), psychological findings and computational models (Cambouropoulos, 2001; Pearce et al., 2010). On the other hand, there are a few studies that has investigated automatic structural analysis of makam musics. Lartillot & Ayari (2009) has used computational models to segment Tunisian modal music and compared the segmentations with the annotations of the experts. Lartillot et al. (2013) has proposed a similar segmentation model for OTMM and also conducted comparative experiments between the automatic segmentations and human annotations. Due to the lack of musicological agreement on how to segment makam music scores, Bozkurt et al. (2014) focused on learning a model from a dataset of music scores annotated by experts and segmenting larger score datasets automatically using the learned model. They propose two novel culture-specific features based on the melodic and rhythmic properties of OTMM and conduct comparative studies with the features used in the state-of-the-art methods and show that the proposed features improve the phrase segmentation performance. 1 These methods typically focus on finding the segment boundaries and do not study the inter-relations between the extracted segments.

In this study, we propose a method which extracts both the melodic and lyrical organization on phrase-level and section-level using symbolic information available in the music scores of Ottoman-Turkish makam music. The method labels the extracted sections and phrases semiotically according their relations with each other using basic string similarity and graph analysis. Our contributions are:

- An automatic structural analysis method applied on Ottoman-Turkish makam music scores
- A novel semiotic labeling method based on network analysis
- An open implementation of the methodology extending our existing score parser
- A dataset of sections and phrases automatically extracted from more than 1300 and 1750 music scores, respectively

The structure of the rest of the paper is as follows: Section 2 describes the OTMM score collection we use in our analysis, Section 3 defines the problem and scope of the analysis task, Section 4 presents the proposed methodology, Section 5 explain the experiments and Section 6 discusses our findings. Section 7 gives the use cases where we have already integrated the extracted structure information, finally Section 8 suggests future directions to be investigated and concludes the paper.

2. SCORE COLLECTION

In the analysis, we use the release v2.4.1 of the SymbTr score collection (Karaosmanoğlu, 2012). 3 This release includes 2200 scores from the folk and classical repertoires.

1 For a detailed review of structural analysis applied to OTMM and relevant state of the art we refer the readers to (Bozkurt et al., 2014) and (Pearce et al., 2010), respectively.

2 The relevant content such as the implementation of the methodology, the score collection, the experiments, the results are also accessible via the companion page http://compmusic.upf.edu/node/302.

3 https://github.com/MTG/SymbTr/releases/tag/v2.4.1
It is currently the largest and the most representative machine-readable score collection of OTMM aimed at research purposes (Uyar et al., 2014). The scores typically note the basic melody of the composition devoid of the performance aspects such as intonation deviations and embellishments. The scores also include editorial metadata such as the composer, the makam, the form, the usual (rhythmic structure) of the composition. We use the scores in txt format in our analysis, as they are the reference format from which the other formats are generated.

The content in the SymbTr-txt scores are stored as “tab separated values,” where each row is a note or an editorial annotation (such as usual change) and each column represent an attribute such as the note symbol, the duration, the measure marking and the lyrics. The pitch intervals are given according to both the 24 tone-equal-tempered (TET) system defined in the Arel-Ezgi-Uzdilek theory and the 53-TET system. The lyrics are synchronous to the note onsets on the syllable level. The final syllable of each word ends with a single space and the final syllable of each poetic line ends with double spaces (Karaosmanoğlu, 2012). Some columns may be overloaded with additional types of information. For example the lyrics row also includes editorial annotations such as the section names, instrumentation and tempo changes, entered in capital letters.

As will be explained in Section 4.1, we use the explicit section names along with the poetic line ends mentioned above in the section extraction step. However, this set of editorial annotations does not convey the complete information about the section boundaries and the section names. First, the section name (and hence the first note of a section) is only given for the instrumental sections and the final note of these sections are not marked at all. Moreover, the section name does not indicate if there are any differences between the renditions of the same section. Regarding the vocal sections, only the last syllable of a poetic line is marked as explained above. This mark does not typically coincide with the actual ending of the vocal section since a syllable can be sung for longer than one note or there might be a short instrumental movement in the end of the vocal section. Out of 2200, 1771 txt-scores in the SymbTr collection has some editorial section information. The remaining 429 scores either lack the editorial section information or they are very short such that they do not have any sections.

3. PROBLEM DEFINITION

As explained in Section 1, symbolic structural analysis is a complex problem that can be approached from different perspectives and granularities. For our initial work in the topic, we assume that the structural elements of the same type are non-overlapping and consecutive (e.g. the last note of a section is always adjacent to the first note of the next section). Consecutiveness restriction also implies that any transitive interactions between two consecutive structural elements are ignored.

Given the note sequence $N := \{n_1, n_2, \ldots\}$ and the measure sequence $M := \{m_1, m_2, \ldots\}$ in the score, our aim is to extract the sections $S := \{s_1, s_2, \ldots\}$ and the phrases $P := \{p_1, p_2, \ldots\}$ (which we call as structural elements collectively, throughout the text) along with their boundaries, and the melodic and lyrical relationship with other structural elements of the same type. We assume each poetic line as a section.

Remark that each subsequence might cover or overlap with subsequences of different types, e.g. the note sequence in a section would be a subsequence of $N$ or a phrase might start in the middle of a measure and end in another. We denote the index of the first note and the index of the last note of an score element $x$ in the note sequence $N$ as $\beta(x)$ and $\gamma(x)$, respectively. For example, the start of an arbitrary section $s_i$, phrase $p_j$ and measure $m_k$ are denoted as $\beta(s_i)$, $\beta(p_j)$ and $\beta(m_k)$, respectively.

4. METHODOLOGY

We first extract the section boundaries from the score using a heuristic process taking the editorial structure labels in the score as an initial reference (Section 4.1). In parallel, we automatically segment the score into phrases according to a model learned from the phrases annotated by an expert (Section 4.2). Next, we extract the synthetic pitch and the lyrics of each section and phrase (Section 4.3). Then, a melodic and a lyrical similarity matrix are computed between the extracted phrases and the sections separately. A graph is formed from each similarity matrix and the relation between the structural elements in the context of the similarity (melodic or lyrical) is obtained (Section 4.4). Finally semantic labeling is applied to the computed relations (Section 4.5).

4.1 Section Extraction

We infer section boundaries using the explicit and implicit boundaries given in the lyrics column of the SymbTr-txt scores (Section 2). As a preprocessing step to distinguish the instrumental section labels from other editorial annotations in the lyrics column, we extract the unique strings in the lyrics column of all SymbTr scores. We only keep the strings, which are written in capital letters and obtain the set of all editorial annotations in the SymbTr-scores. Then, we pick the section annotations manually.

Given a score, we first search the set of instrumental section names in the lyrics column. The matched note indices mark the actual beginning $\beta(s_i)$ of the instrumental sections $s_i \in S \{\lambda(s_i) = \emptyset\}$. Next, the lyrics column is searched for syllables ending with double spaces. The index of the matched notes are assigned to the final note $\gamma(s_i)$ of the vocal sections $s_i \in S \{\lambda(s_i) \neq \emptyset\}$. As explained in Section 2, the index $\gamma(s_i)$ may not coincide

---

4 The unit interval of the 53-TET, which is simply the 1/53th of an octave, is called a Holdierian comma (Hc).
with the actual ending and it may be moved to a subse-
quent note.

Up to here we have found the section sequence $S := \{s_1, s_2, \ldots, s_I\}$, where $I$ is the total number of sections. The first note of the vocal sections and the last note of the instrumental sections are unassigned at this stage. We pro-
cceed to locate the section boundaries using a rule-based scheme iterating though all sections starting from the last one.

If a section $s_i$ is instrumental, the $\beta(s_i)$ is already as-
signed. If a section $s_i$ is vocal and the previous section $s_{i-1}$ is instrumental, we find the last instrumental mea-
sure, $m_k \in M \mid \lambda(m_k) = \emptyset$, before the last note $\gamma(s_{i-1})$ of the section $s_i$. We then assign the first note $\beta(s_i)$ to the first note $\beta(m_{k+1})$ of the next measure $m_{k+1}$. If both the current section $s_i$ and the previous section $s_{i-1}$ are vocal, we assign $\beta(s_i)$ to the index of the first note with lyrics after the last note $\gamma(s_{i-1})$ of $s_{i-1}$. If $\beta(s_i)$ and $\gamma(s_{i-1})$ are not in the same measure, we reassign $\beta(s_i)$ to the first note of its measure, i.e. $\beta(m_k) \mid \beta(s_i) \in m_k$. Finally the last note $\gamma(s_i)$ of the section is moved to the index of the first note $\gamma(s_{i+1})$ of the next section $s_{i+1}$ minus one. The pseudocode of the procedure is given in Algorithm 1. Note that the start of the first section and the end of the final sec-
tion are assigned to the actual ending and it may be moved to a subse-
quent note.

Algorithm 1 Locate section boundaries

\[
\text{for } i := L \rightarrow 1 \text{ do} \quad \triangleright \text{ from the last index to the first}
\]

\[
\text{if } s_i \text{ is vocal then} \quad \triangleright \text{ find } \beta(s_i) \text{ of the vocal section}
\]

\[
\text{if } s_{i-1} \text{ is instrumental then}
\]

\[
\beta(s_i) \leftarrow \arg\min (\beta(m_k) > \beta(s_{i-1}) \land \lambda(m_k) \neq \emptyset)
\]

\[
\text{else} \quad \triangleright \text{ if } s_{i-1} \text{ is vocal}
\]

\[
\beta(s_i) \leftarrow \arg\min (k > \gamma(s_{i-1}) \land \lambda(n_k) \neq \emptyset)
\]

\[
\text{if } \beta(s_i) \in m_k \land \gamma(s_{i-1}) \notin m_k \text{ then}
\]

\[
\beta(s_i) \leftarrow \beta(m_k)
\]

\[
\gamma(s_i) \leftarrow \beta(s_{i+1}) - 1 \quad \triangleright \text{ sections are consecutive}
\]

Having located the boundaries, the sections are extracted by simply taking all information (i.e. rows in the SymbTr-
txt score) between these note boundaries. Figure 1 shows the section boundaries obtained on a mock example.

4.2 Automatic Phrase Segmentation

In our method we use the only automatic phrase segmenta-
tion methodology proposed by Bozkurt et al. (2014) (Sec-
tion 1). The source code and the training dataset (Karaos-
manoğlu et al., 2014) are open and available online.7

In order to train the segmentation model, we apply the an-
notations of Expert 1, who annotated all the 488 scores in
the training dataset (Karaosmanoğlu et al., 2014). There are a total of 20801 training phrases annotated by the first expert. Using the trained model, we apply automatic phrase
segmentation on the score collection (Section 2) and obtain
the phrase boundaries $\beta(p_k)$ and $\gamma(p_k)$ for each phrase $p_k \in P := \{p_1, p_2, \ldots\}$, where $P$ is the automatically
extracted phrase sequence. In Figure 5 (Appendix A), the verti-
cal red and purple lines shows the phrase boundaries extracted from the score “Kimseye Ettem Şikayet.”

4.3 Synthetic Pitch and Lyrics Extraction

We use the information in the lyrics column to determine the boundaries of the vocal sections in Section 4.1. Later, the lyrics of each structural element are extracted in Sec-
ction 4.4 and a lyrical similarity is computed between each structural element of the same type using the extracted.

The lyrics associated with a sequence or an element $x$ is a string denoted as $\lambda(x)$, simply obtained by concatenating
the syllables of the note sequence $\{\beta(x), \ldots, \gamma(x)\}$ of $x$.

The editorial annotations (Section 2) and the whitespaces
in the lyrics column are ignored in the process. Then the char-
ers in the obtained string are all converted to lower case.
Trivially, $\lambda(n_i)$ of a note $n_i$ is the syllable associated with the note $n_i$ in the lyrics column.

Given a subsequence or element $x$ in the score, the syn-
thetic pitch $\rho(x)$ is computed by sampling each note in $x$
according to the note symbol and the duration, and then con-
catenating all of the samples (Şentürk et al., 2014). The
synthetic pitch is used in melodic similarity computation parallel to the lyrics (Section 4.4). Figure 2 shows the
lyrics and the synthetic pitch extracted from an excerpt of the SymbTr-score of the composition “Gel Güzelmî”.

4.4 Melodic and Lyrical Relationship Computation

Given the structure sequence $F := \{f_1, f_2, \ldots\}$ (which is
either the section sequence $S$ or the phrase sequence $P$)
extracted from the score, we first compute the synthetic pitch and extract the lyrics of each structural element (Sec-
tion 4.3). Then, we compute a melodic similarity and lyrical
similarity between each element using a similarity mea-
 sure based on Levenshtein distance (Levenshtein, 1966).

The similarity measure $\hat{L}(x, y)$ is defined as:

\[
\hat{L}(x, y) := 1 - \frac{L(x, y)}{\max \{ |x|, |y| \}}
\]

where $L(x, y)$ is the Levenshtein distance between the two
“strings” $x$ and $y$ with the lengths $|x|$ and $|y|$, respectively
and $\max()$ denotes the maximum operation. In our case, $x$
and $y$ are the synthetic pitch or the lyrics of two structural
elements. The similarity yields a result between 0 and 1.

If the strings of the compared structural elements are ex-
actly the same, the similarity will be one. Similar strings
(e.g. the melodies of two instances of the same section
with volta brackets) will also output a high similarity.

From the melodic and lyrical similarities, we build two
separate graphs, in which the nodes are the structural
and the elements are connected to each other with

7http://www.rhythmos.org/shareddata/
turkishphrases.html

8https://github.com/MTG/SymbTr/blob/
a50a16ab4aa2f30a27861f333ac446737c5a8777/txt/
nihavent--sarki--kapali_curcuna--kimseye_ettem--kemani_sarkis_efendi.txt
undirected edges. The weight of an edge connecting two structural elements \( f_i \) and \( f_j \) is equal to \( \tilde{L}(\rho(f_i), \rho(f_j)) \) in the melodic relation graph and \( \tilde{L}(\lambda(f_i), \lambda(f_j)) \) in the lyrics relation graph, respectively. Next, we remove the edges with a weight less than a constant similarity threshold \( w \in [0, 1] \). In Section 5, we will investigate the effect of using different \( w \) values.

Given the graph, we obtain the groups of structural elements having similar strings by finding the maximal cliques in the graph (Tomita et al., 2006). A maximal clique is a subgraph, which has its each node connected to each other and it cannot be extended by including another node. We denote these cliques as \( v_j \in V \), where \( V \) is the set of “similar cliques.” We additionally compute the maximal cliques of the graph only considering the edges with zero weight. These cliques show us the groups of structural elements, which have exactly the same string. We call each of these cliques as “unique clique” \( u_k \in U \), where \( U \) is the set of the unique cliques. Note that two or more similar cliques can intersect with each other. Such an intersection resembles all the relevant similar cliques. We denote these “intersections” as \( w_l \in W \), where \( W \) is the set of intersections between different similar cliques. Also, \( \eta(x) \) denotes the nodes of an arbitrary graph \( x \). Here we would like to to remark a few relations:

- A unique clique is a subgraph of at least one similar clique, i.e. \( \forall u_k \in U, \exists v_j \in V | \eta(u_k) \subseteq \eta(v_j) \).
- A unique clique cannot be a subgraph of more than one intersection, i.e. \( \forall u_k \in U, \forall \{w_l, w_m\} \subseteq W | \eta(u_k) \subseteq \eta(w_l) \wedge \eta(u_k) \subseteq \eta(w_m) \).

Figure 1: Section analysis applied to a mock example. The section labels (“INTRO” and “FIN”) are given in the lyrics written in capital letters. The spaces in the end of the syllables are visualized as *. The semiotic<br>

\(<\text{Melody, Lyrics}>, \text{label}\) tuples of each section are shown below the lyrics. The similarity threshold in the similar clique computation step is selected as 0.7 for both melody and lyrics.

\[
\begin{align*}
\rho(s) & \equiv \langle \text{melody}, \text{lyrics} \rangle \quad \lambda(s) & \equiv \langle \text{melody}, \text{lyrics} \rangle \end{align*}
\]

Figure 2: A short excerpt from the score of the composition, Gel Güzelim. a) The score, b) the lyrics, c) the synthetic pitch computed from the note symbols and durations. The spaces in the end of the syllables are visualized as *s.

Figure 3: The graphs, the cliques and the semiotic labels obtained from the mock example (Figure 1) using an edge weight threshold of 0.7 for both melody and lyrics. The circles represent the nodes and the lines represent the edges of the graphs, respectively. The edge weights are shown next to the lines. Green, blue and red colors represent the unique cliques, the similar cliques and the intersection of similar cliques, respectively. The semiotic label of each similar clique and each intersection is shown in bold and the semiotic label of each unique clique is shown in italic, respectively.

- A structural element belongs to only a single unique clique, i.e. \( \forall f_i \in F, \exists u_k \in U | \eta(f_i) \subseteq \eta(u_k) \).

4.5 Semiotic Labeling

After forming the cliques, we use semiotic labeling explained in Bimbot et al. (2012) to describe the structural elements. First we label similar cliques with a base letter (“A”, “B”, “C”, ...). Then we label the intersections by concatenating the base letters of the relevant similar cliques (e.g. “AB”, “BDE”, ...). We finally label each
unique clique with the label of the relevant intersection, if exists and with respect to the relevant similar clique otherwise, plus a number according to the occurrence order of the clique in the score. Right now, we only use the simple labels (e.g. \(A_1\), \(A_2\), \(AB_2\)) as termed by Bimbot et al. (2012) to label the unique cliques.

The pseudocode of the process is given in Algorithm 2. During labeling, \(V\), \(W\) and \(U\) are sorted with respect to the index of their first occurrence in the score. We denote the label of an arbitrary element \(x\) as \(\Lambda(x)\). In the algorithm, we also use iterators \(\#(v_j)\) and \(\#(w_i)\) for each similar clique \(v_j\) and each intersection \(w_i\), which are used to assign the numerical index to each unique clique \(u_k\) in \(U\) according to its relation with the relevant similar clique or intersection.

### Algorithm 2 Semiotic labeling

1. \(\lambda \leftarrow "A"\) \(\triangleright\) Start the base letter from \("A"\)
2. \(\#(v_j) \leftarrow 1, \forall v_j \in V\) \(\triangleright\) Init. the iterators for all \(v_j\)
3. \(\#(w_i) \leftarrow 1, \forall w_i \in W\) \(\triangleright\) Init. the iterators for all \(w_i\)
4. For each \(v_j \in \text{sort}(V)\) \(\triangleright\) Label similar cliques
   - \(\Lambda(v_j) \leftarrow \lambda\)
5. For each \(w_i \in \text{sort}(W)\) \(\triangleright\) Label intersections
   - \(\Lambda(w_i) \leftarrow \text{concat}. \Lambda(v_j), \forall \eta(w_i) \subseteq \eta(v_j)\)
6. For each \(u_k \in \text{sort}(U)\) \(\triangleright\) Label unique cliques
   - If \(\exists \eta(w_k) | \eta(w_k) \subseteq \eta(w_i)\) then \(\triangleright\) e.g. "ACD_1"
     - \(\Lambda(u_k) \leftarrow \Lambda(w_i)\#(w_i)\)
     - \(\#(w_i) \leftarrow \#(w_i) + 1\)
   - Else \(\triangleright\) e.g. "C_2"
     - \(\Lambda(u_k) \leftarrow \Lambda(v_j)\#(v_j)\)
     - \(\#(v_j) \leftarrow \#(v_j) + 1\)
7. For each \(f_i \in F\) \(\triangleright\) Label structural elements
   - \(\Lambda(f_i) \leftarrow \Lambda(u_k) | \eta(f_i) \subseteq \eta(u_k)\)

The label of each section of the mock example is shown below the staff in Figure 1. The same semiotic labels are also shown on the computed graphs in Figure 3. Notice that the melodic semiotic label of \(s_0\) is \(B_1\) because the first occurrence of the relevant similar clique is at \(s_2\).

By extracting the relations in the graphs computed from the melodic and lyrics similarity matrices (Section 4.4) and then applying semiotic labeling to each section and phrase according to its relation, we obtain a \(<\text{Melody}, \text{Lyrics}>\) tuple for each section and phrase (Section 4.5). For each phrase we additionally mark the sections, which enclose and/or overlap with the phrase. Appendix A shows the results of the structural analysis applied to the score “Kimseye Etmem Şıkyayet.” We leave the examination of the analysis to the readers as an exercise.

## 5. Experiments

In (Bozkurt et al., 2014) report the evaluation of the phrase segmentation method (Section 4.2) on an earlier and slightly smaller version of the annotations that we use to compute the segmentation model. We refer the readers to (Bozkurt et al., 2014) for the evaluation of the training data. Furthermore, the labels of the automatic phrase segmentations need to be validated by musicologists parallel to the discussions brought by Bozkurt et al. (2014). For this reason, we leave investigating the effects of the similarity threshold \(w\) in phrase analysis as future research.

To observe the effect of the similarity threshold in the melodic and lyrical relationship extraction (Section 4.4), we have collected a small dataset from the SymbTr collection. The test dataset consists of 23 vocal compositions in the şarkı form and 42 instrumental compositions in peşrev and szaszemaisi forms. These three forms are the most common forms of the classical OTMM repertoire. Moreover, their sections are well-defined within music theory; the two instrumental forms typically consists of four distinct “hane”s and a “teslim” section, which follow a verse-refrain-like structure; the sections of the şarkıs typically coincide with the poetic lines. In our initial experiments we focused on şarkıs with the poetic organization “zemın, nakarat, meyan, nakarat,” which is one of the most common poetic organization observed in the şarkı form. Using the automatically extracted section boundaries (Section 4.1) as the ground-truth, the first author has manually labeled the sections in the scores with the same naming convention explained in Section 4.5.\(^9\) Due to lack of data and concerns regarding subjectivity, we leave the evaluation of section boundaries as future research.

We have conducted section analysis experiments on the test dataset by varying the similarity threshold from 0 to 1 with a step size of 0.05. After the section labels are obtained, we compare the semiotic melody and lyrics labels with the annotated labels. We consider an automatic label as “True,” if it is exactly the same with the annotated label and “False,” otherwise. For each score, we compute the labeling accuracy for the melody and the lyrics separately by dividing number of correctly identified (melody or lyrics) labels with the total number of sections. We addi- tionally mark the number of similar cliques and its ratio to the unique cliques obtained for each score. For each experiment, we find the average accuracy for the similarity threshold \(w\) by taking the mean of the accuracies obtained from each score.

Figure 4 shows the notched boxplots of the accuracies, the total number of similar cliques and the ratio between the number of unique cliques and the number of similar cliques obtained for each similarity threshold. For the melody labels, the best results are obtained for the similarity threshold values between 0.55 and 0.80 and the best accuracy is 90%, when \(w\) is selected as 0.70. For lyrics labeling, any similarity value above 0.35 yields near perfect results and 100% accuracy is obtained for all the values of \(w\) between 0.55 and 0.70. In parallel, the number of similar cliques and the ratio between the unique cliques and the similar cliques gets flat in these regions. From these results we select the optimal \(w\) as 0.70 for both melodic and lyrical similarity.

\(^9\) The experiments and results are available at https://github.com/sertansenturk/otmm-score-structure-experiments/releases/tag/fma_2016
As shown in Section 5, the similarity threshold \( w \) has a direct impact on the structure labels. A high threshold might cause most of the similar structural elements regarded as different, whereas a low threshold would result in many differences in the structure disregarded. In this sense the extreme values of \( w \) (around 0 or 1), would not provide any meaningful information as \( w = 0 \) would result in all the structures being labeled similar and \( w = 1 \) would be output all the structures as unique. We also observe that the melodic similarity is more sensitive to value of \( w \) than lyrics similarity. This is expected as the strings that make up the lyrics are typically more diverse than the note symbols used to generate the synthetic pitch. In our experiments we found the optimal value of \( w \) as \( 0.7 \) for the small score dataset of compositions in the peşrev, sazsemaisi and şarkı forms. Moreover we observe that the curves representing the number of similar cliques and the ratio between the unique cliques and the similar cliques are relatively flat around the same \( w \) value, where we obtain the best results (Figure 4). This implies that there is a correlation between decisions of the annotator and our methodology.

Nevertheless, we would like to emphasize that the \( w \) value found above should not be considered as a general optimal. First of all, the sections were annotated by a single person and therefore our evaluation does not factor in the subjectivity between different annotators. Second, the section divisions in different forms are much different from the forms we have experimented upon, which might influence the structure similarity. For example, we expect many vocal compositions of OTMM with “terennüm”’s (repeated words with or without meaning such as “dost,” “aman,” “ey”) need a lower similarity threshold in the lyrics relationship computation step. Moreover the poetic lines might not coincide with melodic sections in many vocal compositions especially in folk music genre. Third, the threshold can be different in different granularities. For example, the phrases are much shorter than the sections as can be seen in Appendix A. The human annotators might perceive the intra-similarity between sections and phrases differently.

7. APPLICATIONS

We have implemented the structural analysis methodology in Python and integrated it to the symbtrdataextractor package, a SymbTr-score parser written by us. \(^{10}\) We have also forked the open automatic phrase segmentation package by Bozkurt et al. (2014), which is written in MATLAB scripting language. The fork modularizes the code and packages it into a standalone binary so it can be integrated to other tools without the need of a MATLAB proprietary license. Moreover, the code is optimized such that it performs considerably faster than the original code. \(^{11}\) We have been using the information extracted from the structural analysis in several applications:

**Score collection analysis:** Using the optimal similarity threshold \( (w = 0.7) \), we applied structural analysis on the latest release of the SymbTr collection (Section 2). We have extracted and labeled 49259 phrases from 1345 scores, which have both their makam and usul covered in the phrase segmentation training model. Because there is no training data for the usul variants “Yürüksemai II”, “Devrihindii II”, “Müsemmen II”, “Raksaksadga II”, “Devirturan II” and “Kapalı Curcuna,” we treat them as the most common variant of the same usul, namely “Yürüksemai”, “Devrihindii”, “Müsemmen”, “Raksaksadga”, “Devirturan” and “Curcuna”. In parallel, 21569 sections are extracted from 1771 scores. \(^{12}\) The data can be further used to study the structure of musical forms of OTMM.

**Automatic score validation:** Structural analysis, along with the other functionalities of the symbtrdataextractor package are used in unitests applied to SymbTr collection in a continuous integration scheme to automatically validate the contents of the scores. \(^{13}\)

**Score format conversion:** We are currently developing tools in Python to convert the SymbTr-txt scores to the MusicXML format \(^{14}\) and then to the LilyPond format \(^{15}\) to improve the accessibility of the collection from popular music notation and engraving software. The converters use the information obtained from symbtrdataextractor to add the metadata and the section names in the converted scores.

**Audio-score alignment:** In the performances of OTMM compositions, the musicians occasionally insert, repeat and omit sections. Moreover they may introduce musical passages, which are not related to the composition (e.g. im-

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\(^{10}\) https://github.com/sertansenturk/symbtrdataextractor

\(^{11}\) The fork is hosted at https://github.com/MTG/makam-symbolic-phrase-segmentation

\(^{12}\) The data is available at https://github.com/sertansenturk/turkish_makam_corpus_stats/tree/66248231e4835138379ddeac970eabf7dad2c7f8/data/SymbTrData

\(^{13}\) https://travis-ci.org/MTG/SymbTr/

\(^{14}\) https://github.com/burakuyar/MusicXMLConverter

\(^{15}\) https://github.com/hsercanatli/makam-musicxml2lilypond
provisions). In (Şentürk et al., 2014), we have proposed a section-level audio-score alignment methodology proposed for OTMM, which considers such structural differences. In the original methodology the sections in the score are manually annotated with respect to the melodic structure. Next, the candidate time intervals in the audio recording are found for each section using partial subsequence alignment. We replaced the manual section annotation step with the automatic section analysis part of our alignmet method, where we use the melody labels to align relevant audio recordings and music scores. Using the modified method we have aligned the related audio and score pairs in the CompMusic Turkish makam music corpus (Uyar et al., 2014) and linked 18,770 sections performed in 1,767 pairs of audio recordings and music scores. The aligned audio-score pairs are accessible via Dunya makam, our prototype web application for the discovery of OTMM (Şentürk et al., 2015). In the application, the audio can be listened synchronous to the related music score(s) on the note-level and the sections are displayed on the audio timeline.

We have additionally conducted experiments using the melodic relations of the extracted phrases. Our preliminary results suggest that phrase-level alignment may provide better results than section-level alignment.

8. CONCLUSION

We proposed a method to automatically analyze the melodic and lyrical organization of the music score of OTMM. We applied the method on the latest release of the SymbTr collection. We extracted 49,290 phrases from 13,45 scores and 21,569 sections from 1,771 scores. We are also using the extracted structural information in automatic score validation, score engraving and audio-score alignment tasks.

In the future, we would like to test other string matching and dynamic programming algorithms (Serrà et al., 2009; Şentürk et al., 2014) in general, for similarity measures with different constraints and select the optimal similarity threshold w automatically according to the melodic and lyrical characteristics of the data. We would also like to solidify our findings by working on a bigger dataset annotated by multiple experts and cross-comparing the annotated and the automatically extracted boundaries as done in (Bozkurt et al., 2014). Our ultimate aim is to develop methodologies, which are able to describe the musical structure of many music scores and audio recordings semantically and on different levels.

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10. REFERENCES


16 http://dunya.compmusic.upf.edu/makam
Figure 5: The results of the automatic structural analysis of the score “Kimseye Etmem Şikayet.” The sections are displayed in colored boxes with the volta brackets colored with a darker shade of the same color. The section labels and their semiotic \(<\text{Melody, Lyrics}>\) label tuple is shown on the left. The phrase boundaries are shown as red lines for the first and as purple for the second pass. The phrases and their semiotic labels are shown on top of the relevant interval and on the bottom, when there are differences in the boundaries in the second pass. Note that \(s_5, s_6, s_9\) and \(s_{10}\) are the repetitive poetic lines (tr: “Nakarat”). “[Son]” in the end of the “Nakarat” marks the end of the piece. The similarity threshold is taken as 0.7 for both melody and lyrics. The usul of the score is \(\text{Kapalı Curcuna}\), which we treat as \(\text{Curcuna}\) in the phrase segmentation step.