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Chord Function Identification with Modulation Detection Based on HMM

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Along with the development of computer science, a large variety of research attempts to externalize human intuition, such as natural language understanding. Since music has similar aspects to natural language, we should consider applying the approaches of natural language processing (NLP) also to music, however, we need to take care of unique features that are different from language. Music is made from multiple normative structures, e.g., harmonic structure, metrical structure, and so on. Among existing structures, we focus on the theory of functional harmony that regulates the role of chords, and decides the key. Especially, we expect that the harmonic analysis and the key determination can be processed simultaneously as one and the same effort.

In the area of computational music research, the key detection and the function of chords acquisition have been researched independently. The key detection algorithms are mainly based on histogram of the pitch classes which referred as the key-profile, representing the importance of each pitch class in a key. The key-profile is originally obtained by a psychological experiment. Recent studies show that it can be learned statistically. Although the histogram based key detection algorithms are widely used, they need to specify the scope on the score for applying the algorithm.

An existing previous work employs the distance between chords such as Tonal Pitch Space (TPS) rather than the pitch classes. The key is detected by the Viterbi algorithm, not requiring a fixed scope. TPS defines the distance between chords in a uniform way, and thus, cannot consider the difference of music styles.

Statistical learning is a solution to consider the difference of music styles. Previous research found the function of chords, achieved statistically. There are two mainstreams, the classification of chords and generative modeling. Generative models are more advantageous because of their predictive power, and can be applied to many applications.

Generative models are, in general, difficult to fix the appropriate size, such as the number of hidden states of the Hidden Markov Model (HMM). Although the perplexity of the output probability is prone to decrease when the number of hidden states of HMM increases, a larger number of them may be not always meaningful.

This research presents a new approach. We consider the performance of the key detection when obtaining the model size. In this research, we employ two algorithms: the generative modeling of the function of chords, and the

key detection using the set partitioning problem. We use the choral pieces written by J.S.Bach as our dataset.

We modeled the function of chords of major key and minor key by HMM, and investigated the number of hidden states among 2 and 12. To learn the models, we transposed all the major keys to C-major, while all the minor ones to a-minor. A thousand different initial values were tested to learn the parameters, and the optimal values are ranked by the perplexity.

The result shows that the minimum perplexity of output probabilities decreases along with the increase of the number of hidden states. While the distances of the optimal values also increase along with the number of hidden states. This suggests that there would be many optimal values in the parameter space and it is difficult to fix a robust solution when the number of hidden states is large.

We apply the proposed key detection algorithm to obtain the appropriate number of hidden states. To this purpose, we select a key to maximize the log output probability, calculated by the obtained HMM. The pitch of target chord sequence is transposed to a possible set of candidate keys, among which one that is the nearest either to C-major or to a-minor would be chosen.

The algorithm above can select one optimal key to one target chord sequence. Using the set partitioning algorithm is a solution to detect modulations, so that we can obtain the optimal key blocks to one target chord sequence. The function of chords should work well to detect a key, especially when there are modulations in the target sequences. To investigate the appropriate model size, the sum of log probabilities of detected key blocks of all pieces in dataset is used. The obtained result shows that the model with 6 hidden states is best for both of major and minor keys.

The major key parameters with 3 hidden states are very similar to the knowledge of the functional harmony theory, resulting the hidden state of Tonic, that of Dominant, and that of Subdominant. However, the chords are classified into finer-grained functions, up to 6 hidden states. When the number of hidden states is 4, the state for Subdominant is separated into two: {**IV**,**ii**} and {**vi**}, as well as the that of Dominant is separated into {**V**} and {**vii°**} with 5 hidden states. Finally, when the number of hidden states is 6, each chord is assigned to each hidden state.

The results of minor-scale are significantly different from that of major-scale, hidden states correspond to Tonic and Dominant of the relative major key are obtained when the number of hidden state is larger than 4. With 6 hidden states, in addition to Tonic, Dominant and Subdominant, the Tonic of relative major and that of Dominant of relative major are obtained. This result reflects the feature of choral, whose melody was composed in the middle ages in Gregorian modes instead of modern tonalities, prior to the harmo-

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nization by J.S.Bach, because the relative keys share the common pitch class in Gregorian modes.

This research showed the appropriate model size of HMM by considering the performance of the key detection. In contrast to the evaluation with perplexity, the selected number of hidden states is not large, so that obtained parameters are meaningful. Since the parameters also reflect the musical style of the corpus pieces, our approach has a potential to be applied different music styles, such as music in post-romanticism. In addition, we present the new algorithm, which can detect modulation automatically without giving fixed scope and works well since the distance between chords have been learned statistically using the dataset.

Although we have realized the efficient performance in our research, we need to admit that our approach could include several mistakes in key detection, which sometimes treats small groups of chords as a modulation. This is because HMM cannot represent more external structures such as cadence. In the future, we will consider more sophisticated approaches, for example, introducing dependency of music structures into model.