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Harmony Analysis based on Tonal Pitch Space

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Every chord can be interpreted as a key and degree pair in several ways. Although we cannot say which is the best interpretation for an individual chord, this situation changes when the chord is put into a context (*i.e.* chord sequence). In this thesis we propose the way to refine the method to estimate an interpretation for each chord given a context.

Tonal Pitch Space (TPS) gives us a numerical distance between two chords which reflects human perception. Sakamoto *et al.* have proposed a method to determine the most plausible (*i.e.* sounds natural for humans) interpretation sequence for a chord sequence by making a graph of all possible interpretations whose edges have weights correspond to the distances calculated by TPS and finding the shortest path in the graph. However, there are several limitations: (1) tetrads (e.g. seventh chords) are not considered, (2) natural/harmonic/melodic minor scales are not distinguished, (3) every chord has only one interpretation in an interpretation path, (4) direction is not considered, and (5) relations among more than two chords are not considered. Because these limitations tend to result in somewhat coarse analysis especially for jazz, the number of shortest paths often becomes enormous.

To overcome these limitations, in the first study we propose three extensions on TPS and interpretation graph. First, we incorporate tetrads and distinction of three minor scales (i.e. natural, harmonic, and melodic minor scales) in TPS to deal with the issues on (1) and (2). Second, we introduce ϵ-transition, which is a notion in automata theory, that tolerates 'free' shift in states, into the interpretation graph, in which a chord progression is regarded as a state change from vertex to another. This ϵ-transition, however, allows us to reread a chord name to another without progression. This contributes the interpretation of pivot chord, and thus solves (3). Third, we introduce the notion of cadential shortcuts to solve (4) and (5). If a certain sequence of chords matches a typical progression of cadences, we can skip the intermediate progressions and can jump to the cadences. This kind of shortcuts explicitly gives us the direction of chord progression to solve (4), and they enable us to consider tri-grams (or more) to solve (5). We show, these three extensions give not only more detailed but also less ambiguous estimations which result in the significant reduction of the number of shortest paths. Furthermore, we conduct chord reharmonization and cadence evaluation as examples of applications of our method.

In the next study, we deal with the other limitations in TPS and interpretation graph, namely, arbitrariness and low prediction accuracy. We first

rearrange the distance formula in TPS to the sum of three distance elements (*i.e.* those of region, chord, and basic space), and then generalize it to allow us to add other distance elements which we define in the form of table. Next, we introduce a novel probability formula which gives higher probability to a shorter path. With this, we can convert a total distance of an interpretation path to a path probability and then a cross-entropy loss function with which we can calculate the gradient with respect to the parameters to update them. This framework enables us to define distance elements selecting features freely and give their parameters the appropriate values backed by data. We propose several distance elements and show the best one can considerably improve the prediction accuracy (86.9%).