Three-Level Model for Fingering Decision of String Instruments

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Abstract. Fingering decisions of string instruments and other instruments differ in that the former involves string assignments as well as finger assignments while the latter is simply a matter of assigning fingers to notes. The present study introduces a three-level model for fingering decision of string instruments to describe the structure of the problem and present problem settings of fingering decision based on the model. Our proposed three-level model provides clear perspective for some problem settings of fingering decision. We perform a simulation to demonstrate the flexibility of the three-level model.

Keywords: fingering decision, string instruments, hidden Markov model(HMM)

1 Introduction

String instruments have overlaps in pitch ranges of their strings. As a consequence, they have more than one way to play even a single note and thus numerous ways to play a whole song. That is why the fingering decision for a given song is not always an easy task for string players and therefore automatic fingering decision has been attempted by many researchers. As for applications of HMM to fingering decision, Hori et al.[1] applied input-output HMM to guitar fingering decision and arrangement, Nagata et al.[2] applied HMM to violin fingering decision, and Nakamura et al.[3] applied merged-output HMM to piano fingering decision. Hori and Sagayama.[4] and Hori[5] proposed extensions of the Viterbi algorithm for fingering decision.

The purpose of the present study is to point out that fingering decisions of string instruments and other instruments differ in that the former involves string assignments as well as finger assignments while the latter is simply a matter of assigning fingers to notes. To describe the structure of fingering decision of string instruments, we introduce a three-level model for string instruments and provide a unified way of looking at variations of problem settings of fingering decision. Our proposed three-level model provides clear perspective for some problem settings of fingering decision. We perform a simulation to demonstrate the flexibility of our three-level model with fingering decision from score with finger numbers.

The rest of the paper is organized as follows. Section 2 reproduces the guitar fingering decision model based on HMM[1]. Section 3 points out the difference in fingering decision between string instruments and other instruments and introduces the three-level model. Section 4 presents problem settings of fingering decision based on the three-level model and Section 5 performs a simulation for one of the problem settings. Section 6 concludes the paper.

2 Fingering Decision Based on HMM

This section reproduces the guitar fingering decision model based on HMM[1] whose output symbols are musical notes and hidden states are left hand forms, which corresponds to the problem setting of Section 4.1 in this paper. Although we use the monophonic case as an example to simplify the explanation in the following sections, the results apply to the polyphonic case as well. See [1] for details of the polyphonic case.

2.1 HMM for fingering decision

To play a single note with a guitar, a guitarist depresses a string-fret pair p_i on fretboard,

$$p_i = (s_i, f_i),$$

with a finger h_i of the left hand and picks the string with the right hand. Therefore, a left hand form q_i for playing a single note can be expressed in a triplet q_i,

$$q_i = (s_i, f_i, h_i),$$

where $s_i = 1, \ldots, 6$ is a string number (from the highest to the lowest), $f_i = 0, 1, \ldots$ is a fret number, and $h_i = 1, 2, 3, 4$ is a finger number of the player's left hand (1,2,3 and 4 means the index, middle, ring and pinky fingers). The fret number $f_i = 0$ means an open string. The MIDI note number of the note played by the form q_i is calculated as follows where o_{s_i} denotes the MIDI note number of the open string s_i,

$$n(q_i) = o_{s_i} + f_i.$$

In this formulation, fingering decision is cast as a decoding problem of HMM where a fingering is obtained as a sequence of hidden states q_i given a score as a sequence of output symbols n_k.

2.2 Transition and output probabilities

The difficulty levels of the moves from forms to forms are implemented in the probabilities of the transitions from hidden states to hidden states; a small value of the transition probability means the corresponding move is difficult and a large value means easy. We assume that the four fingers of the left hand are always put on consecutive frets in this paper for simplicity. This lets us calculate the *index finger position* (the fret number the index finger is put on) of form q_i as $g(q_i) = f_i - h_i + 1$. Using the index finger position, we set the transition probability from hidden state q_i to hidden state q_j as

$$a_{ij}(d_t) \propto \frac{1}{2d_t} \exp\left(-\frac{|g(q_i) - g(q_j)|}{d_t}\right) \times P_H(h_j) \tag{1}$$

where $\propto$ means proportional and the left hand side is normalized so that the summation with respect to j equals 1 for all i. The first term of the right hand side is taken from the probability density function of the Laplace distribution that concentrates on the center and its variance d_t is set to the time interval between the onsets of the $(t-1)$-th note and the t-th note. The second term $P_H(h_j)$ corresponds to the difficulty level of the destination form q_j defined by the finger number h_j.

As for the output probability, because all the hidden states have unique output symbols in our HMM for fingering decision, it is 1 if the given output symbol n_k is the one that the hidden state q_i outputs and 0 if the given output symbol is not,

$$b_{ik} = \begin{cases} 1 & (\text{if } n_k = n(q_i)) \\ 0 & (\text{if } n_k \neq n(q_i)) \end{cases} . \tag{2}$$

3 Three-Level Model for Fingering Decision of String Instruments

This section identifies the fundamental difference in fingering decision between string instruments and other instruments, and then introduces a three-level model for fingering decision of string instruments.

3.1 Note-tablature-form tree

For example, on the piano, there is only one key on the keyboard to press for each note, and therefore fingering decision for a given sequence of notes is a matter of deciding which finger to press on the key for each note (Fig.1, right). On the other hand, with the guitar, each note corresponds to several string-fret pairs that play it, and in addition, we have a matter of which finger to press for each string-fret pair (Fig.1, left). In other words, fingering decision for the piano is simply a matter of finger assignments, while fingering decision for the guitar consists of string assignments followed by finger assignments. This situation with the guitar is illustrated in a tree diagram (Fig.1, left) which we call "note-tablature-form tree." While the tree diagram in Fig.1 is for a monophonic note, we can draw the same diagrams for a polyphonic chord as well.

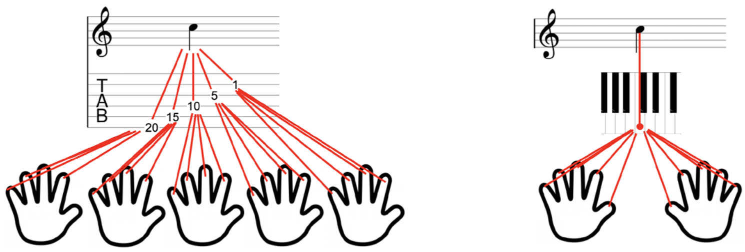

Fig. 1. Note-tablature-form tree for guitar (left) and corresponding diagram for piano (right) illustrating difference between string instruments and other instruments

3.2 Three-level model

To describe the above-explained situation with fingering decision of string instruments, we introduce a three-level model for string instruments that consists of (1) note level, (2) tablature level, and (3) form level (Fig.2). In relation to the notation introduced in Section 2.1, the note level contains the information of $n(q_i)$, the tablature level

$p_i = (s_i, f_i)$, and the form level $q_i = (s_i, f_i, h_i)$, respectively. In guitar scores, the score and the tablature contains the information of the note level and the tablature level, respectively. The finger numbers attached to the notes in the score, together with the tablature, make up the information of the form level (see Section 4.3). From the viewpoint of fingering decision based on HMM, the hidden states corresponds to the form level and the setting of observed symbols varies depending on the problem settings as we will see in the following sections.

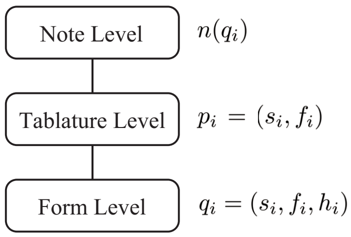

Fig. 2. Three-level model for fingering decision of string instruments

4 Problem Settings Based on Three-Level Model

This section provides a unified way of looking at variations in problem settings of fingering decision based on the three-level model for string instruments, taking the guitar as an example. Fingering decision is cast as a decoding problem of HMM where the setting of observed symbols varies depending on the problem settings. The first problem is a conventional one while the second and third ones obtain clear perspectives in light of our proposed three-level model.

4.1 Fingering decision from score

In this problem setting, we generate a sequence of forms from a score, taking the note level as the observed symbols and the form level as the hidden states (Fig.3, left). This is a conventional and common problem setting in guitar fingering decision and has been well studied including our previous study[1]. Here we note that the transition probability reflecting the difficulty of the form transition can be defined only in the form level and not in the tablature level, which we can see from the formula of transition probability (1). Even when we only need to generate tablature, we have to perform HMM decoding in the form level.

4.2 Fingering decision from tablature

In this problem setting, we generate a sequence of forms from a tablature, taking the tablature level as the observed symbols and the form level as the hidden states (Fig.3, right). Here we note that a tablature shows only string assignments for notes and does not contain information of finger assignments, although it is easy for skilled guitarists to find appropriate finger assignments and thus a fingering for a given tablature. An application example of this problem setting is difficulty assessment of a tablature where the difficulty is calculated as the reciprocal of the product of the transition probabilities along the generated sequence of forms.

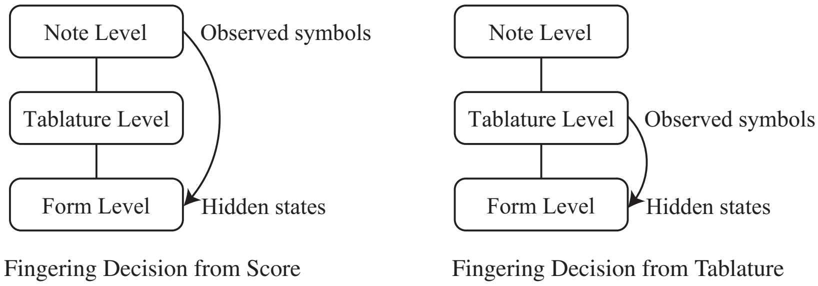

Fig. 3. Two problem settings based on three-level model

4.3 Fingering decision from score with finger numbers

There are guitar scores without tablatures with finger numbers attached to some key notes (Fig.4, left), which is enough for skilled guitarists to find a fingering for whole phrase. From the viewpoint of our proposed three-level model, this is a case where the whole information of the note level and the partial information of the form level are given to generate a sequence of forms. The fingering decision in this case is implemented as a decoding problem of HMM whose observed symbols are the notes and hidden states are forms limited to ones with indicated finger numbers. We will see some simulation results of this problem setting in the following section.

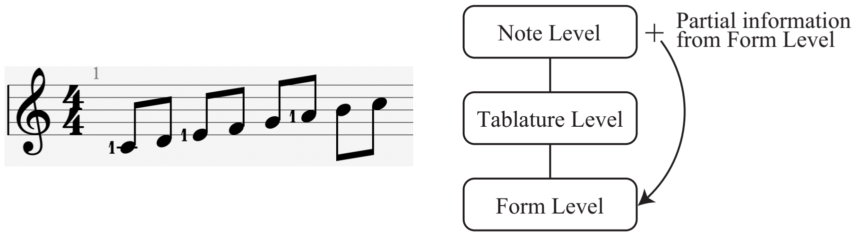

Fig. 4. Score with finger numbers (left) and corresponding problem setting (right)

5 Simulation

From the problem settings described in the previous section, we perform a simulation of one presented in Section 4.3 to demonstrate the flexibility of our proposed three-level model. The results for four scores are given in Fig.5 where the sequence of notes (C major scale) is common to all and the finger numbers with red circles are given while other finger numbers and the tablatures are generated by HMM. In the transition probability (1), we set $P_H(1) = 0.4$, $P_H(2) = 0.3$, $P_H(3) = 0.2$ and $P_H(4) = 0.1$ which means forms using the index finger are the easiest and the pinky finger the most difficult. From the results, we see that HMM generates appropriate fingerings for all the scores minimizing change in the index finger position and that specifying a finger number to one note can change fingerings for the rest seven notes.

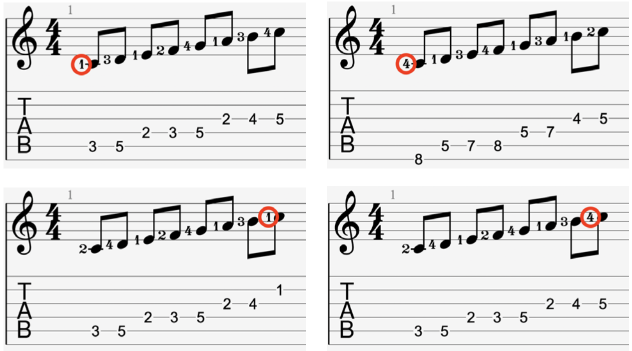

Fig. 5. Simulation results of fingering decision from score with finger numbers

6 Conclusion

We have pointed out the difference in fingering decision between string instruments and other instruments and introduced a three-level model for fingering decision of string instruments. Based on the model, we have provided a unified way of looking at three variations in problem settings of fingering decision and demonstrated the flexibility of our proposed three-level model using a simulation for fingering decision from score with finger numbers. There are other instruments than string instruments for which we have more than one way to play a single note. For such instruments, we can consider a fingering model with a middle level corresponding to the tablature level of our model for string instruments. We leave the extension of our three-level model to such instruments to our future study.

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