Conversion from Standard MIDI Files to Vertical Line Notation Scores and Automatic Decision of Piano Fingering for Beginners

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ABSTRACT

This paper introduces a method for converting standard MIDI files to the "vertical line notation" (VLN) and an algorithm for automatic decision of piano fingering for beginners.

Currently, staff notation is widely used for various instruments including piano. However, this notation often appears hard to beginners. On the other hand, VLN is intuitive and easy to understand for piano beginners since it graphically indicates the time order of notes as well as fingering. With the VLN score, piano beginners can make smooth progress with correct fingering, and it is expected to be useful for early education in music.

A problem with VLN is that it is currently created by hand with a spreadsheet software. It would be desirable to automatically produce VLN scores from existing digital scores.

Our proposed method can solve above problem. In addition, this paper also presents some examples of practical and successful use of VLN scores.

1. INTRODUCTION

Among many existing types of music notations including staff notation, tablature notation for guitar and luto, one line notation for percussion, graphic notation, numeral notation, and Japanese traditional notation [1], staff notation is most commonly used for a wide variety of musical instruments.

Notations have evolved to express composer's intentions as accurately as possible, and therefore, they became advanced and complex with the times. For instance, staff notation provides musician with a variety of information, including pitch, accidentals, note length, dynamics, trills, turns, articulations (including staccato, tenuto, accent and attack), etc.

However, to music beginners, it is difficult to read even pitch and the length of a note in staff notation. For this reason, in many cases, people who are not accustomed to play the piano often give up in the process of reading a staff notation scores, even for a short musical piece and simple melody (see section 3.4).

With this background in mind, in 1985, Suguru Agata proposed vertical line notation (VLN) which is designed by piano roll style for the piano beginners [2]. It is very easy to understand the pitch of notes on a VLN score, and it can also show piano finger numbers.

In this paper, we first review how to read VLN scores. Next, we explain a conversion method from standard MIDI files to VLN scores, and propose an automatic decision of piano fingering for the piano beginners. Moreover, we show applied examples in which piano beginners could play the piano easily using VLN scores.

2. VERTICAL LINE NOTATION

Figure 1 illustrates how to read a VLN score. In a VLN score, the horizontal direction expresses note pitch; the left side is for lower pitches and right side is for higher pitches. The vertical direction shows time flow; the direction toward the bottom represents the progression of the music.

The horizontal positions of circles represent the pitch of notes while blue bars designate the temporal order of notes. We call the circle "node" and the bar "link," after the research field on graphical model [3]. Each node contains a finger number. Therefore even piano beginners can play a musical piece with correct fingering very easily. They only need to strike the keys by following the finger numbers in the nodes. For piano players, it is very important to get into the habit of playing with correct fingering. The link shows whether the pitch of the next node is higher or lower than the current node. This is useful in searching for the next node.

Figure 2 shows an example of staff notation score of a children's song "tulip." Figure 3 shows a VLN score of the song "tulip." This VLN score is made for Japanese children or for older persons, so the title is written on the top of the VLN score in hiragana letters. The lyrics are also written on the left side using hiragana letters.

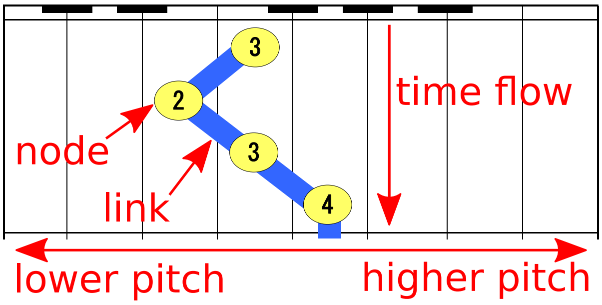


Figure 1. Format of VLN score.

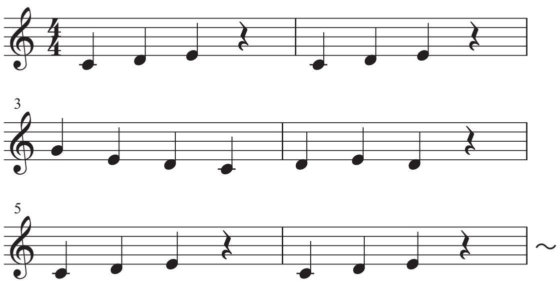


Figure 2. Staff notation score of a children's song "tulip."

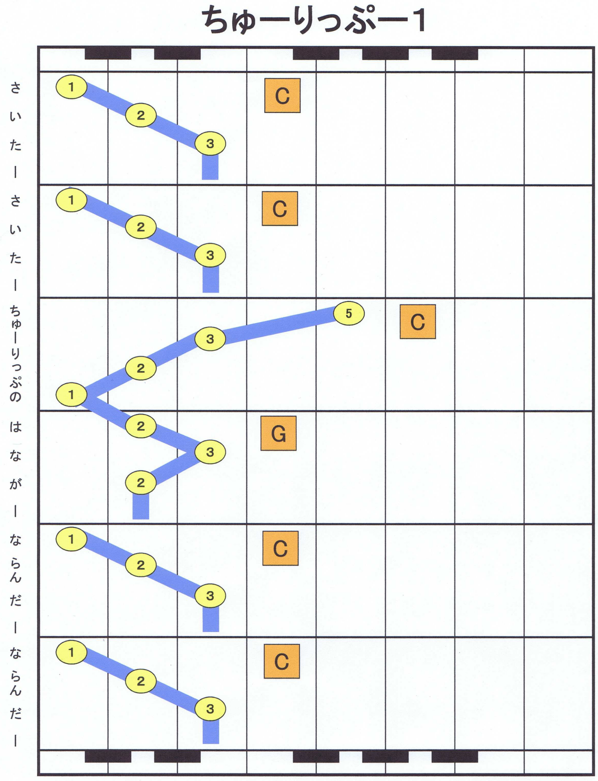


Figure 3. VLN score (handmade) of "tulip" with Japanese lyrics.

If the appropriate adjustment of magnification ratio of a VLN score is achieved, the graph of keys in the VLN score can be made to correspond to the keys of a real piano keyboard. As a result, the piano player can easily find the key to be pressed on the keyboard just below the node. Moreover, because a VLN score always shows real pitches, it is not influenced by key and clef sign in staff notation. In contrast, in the staff notation, pitch is shown as vertical position, and therefore the correspondence of pitch in staff notation to piano keyboard is not intuitive.

At the same time, it would be necessary for the beginners to gradually be capable of reading staff notation. We will discuss the transition from using VLN scores to staff notation scores in Section 8.3.

3. PERFORMANCE BY USING VLN SCORES

3.1 Beginners' piano class for senior persons in Showa Univ. of Music

We began a beginners' piano class for elder people in Showa University of Music in 2010. The age of participants is from 60s to 80s. In this piano class, we have used electronic keyboards. Figure 4 shows the configuration of the piano class.

In the lesson, we teach through three stages instead of playing music from the beginning. First, the participants hit table by finger in accordance with VLN score. In this stage, the participants concentrate on only correct order of the finger without much attention to the position of key on the keyboard.

Second, while turning off the power of the electronic keyboard, they practice key strokes. Even if they make mistakes in the fingering, they need not to worry about it. The important things are to continue until the end, and not to be afraid to fail. This "silent practice" characteristics is unique to the electronic keyboard, and cannot be done on the acoustic piano.[*1]

Third, participants play the music with sound after turning on the electronic keyboard.

We have found the all the participants can play the piano and have enjoyed the practice.

3.2 Piano class in Rest Villa Ebina

We have held piano classes with VLN scores at Rest Villa Ebina which is a private facility providing long-term care to the elderly. Figure 5 shows the situation. In this photo, two persons use wheelchairs. One of the residents of the facility suffers from Parkinson's disease. The upper half of her body usually leaned to the right side. However, her posture has improved, since she started the keyboard performance using VLN scores. In addition, her speech ability has also changed for the better, and she has been able to evaluate the performance of others. It is considered that muscle and brain are activated by playing the keyboard, and we suggest that VLN score can be effectively utilized in the welfare field and it gives purpose in life for senior persons.

If we had used a complex staff notation score, people might have lost interest. However, by using the VLN score,

[*1] The same effect is obtained by using acoustic pianos with "silent mode", for example, YAMAHA Silent Piano series.

Figure 4. Piano class for senior people at Showa Univ. of Music.

Figure 5. Piano class for senior people at an elderly persons' home.

they have been interested in the piano performance, and they have practiced enthusiastically.

3.3 Beginners' piano class for students at NITKC

We tried to apply VLN scores to piano class for young people. We held a beginners' piano class for students at the National Institute of Technology, Kisarazu College (NITKC) in May 2015. Actually, 13 students who were interested in playing the piano volunteered for this class. They experienced the same three stage practice method as the senior persons. Amazingly, after 90 minutes of practice, they could play the piano using both hands.[*2]

3.4 Open campus at NITKC

In open campus at NITKC, various studies are introduced to junior high school students and their parents. We explained the automatic accompaniment system (AAS). The name of the AAS is "Eurydice". This AAS is developed by

[*2] Some video clips are shown in the following Website: `http://beam.kisarazu.ac.jp/~saito/research/VLN/`

Figure 6. Piano class for students at Nat. Inst. of Tech., Kisarazu College.

Figure 7. Piano performance by a junior high school student in open campus of NITKC. She could play the VLN score at sight.

using C++ language on "Qt" which is a cross-platform development framework for graphical user interface (GUI). Eurydice deals with MIDI signals; the input MIDI signal is given from MIDI piano as performance data of human player, and the output MIDI signal is accompaniment data [5]. A standard MIDI file (SMF) as musical score information is given to Eurydice in advance, and the AAS estimates a musical score position of the performance of the human player. Eurydice allows errors in performances such as insertion of unnecessary notes, deletion of notes, and lack of accidentals. Notably, Eurydice is the world's first system that allows arbitrary jumps; the human player may practice playing the same bars again and again, or go to a later section of the score by skipping over some bars; in either case Eurydice follows the player's performance.

Until 2014, we have used staff notation at the presentation. At first, as a performance example, we played a melody of a short piece of music, and Eurydice played an accompaniment part at the same time. After that, we asked junior high school students to play the music. However, most of the students did not try to perform on the piano.

In 2015, we explained VLN and demonstrated performance by using a VLN score with Eurydice. Figure 7 shows the piano performance. Consequently, all the junior high school students who visited our demonstration (about 20 persons) tried playing the piano, and performed to the end at sight without regular practice. We consider that the psychological distance for piano of junior high school students is shortened by using VLN score.

4. AUTOMATIC CONVERSION FROM SMFS TO VLN SCORES

Currently, VLN scores are made by using Microsoft Excel or fully hand written. The work takes a long time and is laborious. Therefore, it would be desirable to automatically produce VLN scores from existing digital scores.

There are several formats of digital score such as standard MIDI file (SMF), MusicXML, and custom formats of music score editors. Among these formats, SMF is the most widely used. It is easy to make SMFs by using commercial or free music software. Fortunately SMFs are distributed on the internet, in that case, people do not need to make SMFs themselves. This is a great advantage. We implemented a conversion system from SMFs to VLN scores [4].

4.1 MIDI standard

Musical instrument digital interface (MIDI) is a universal standard for the digital transmitting of performance data between electronic musical instruments [5]. It consists of certain standards, such as a physical transceiver circuit and interface, a communication protocol, a file format, etc. Transmission and reception of data on the MIDI standard are all carried out in MIDI messages. A MIDI message is constructed of plural bytes (8 bits per one byte). To transmit MIDI messages efficiently, the bytes which express MIDI messages are divided into two types: a "status byte" and a "data byte." The status byte has "1" as the most significant bit (MSB); namely, it contains 128 data types from 80H to FFH in hexadecimal format. In contrast, the data byte includes "0" as the least significant bit (LSB). Thus the range of the data is from 00H to 7FH.

4.2 Formats of SMF

There are three types of formats of SMFs. The format 0 has only one track which includes all note information. It is equivalent to mixed down music data. Therefore, this format is for the purpose of playback only. The format 1 can contain many independent tracks. This format easily deals with decomposed data on a MIDI sequencer. The format 2 has multitracks and multisequence patterns. In the case of playing the SMF format 2 data, one of the sequence patterns is chosen in each track. This format seems to have been originally developed and intended for use in, for example, karaoke. However, it is little used in other practice.

The SMF is composed of several parts. One is the "header chunk," which includes information of the whole SMF. The other is the "track chunk," which contains real performance data.

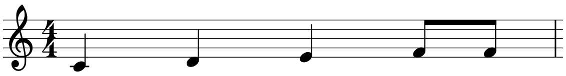


Figure 8. An example score in staff notation which includes eighth notes.

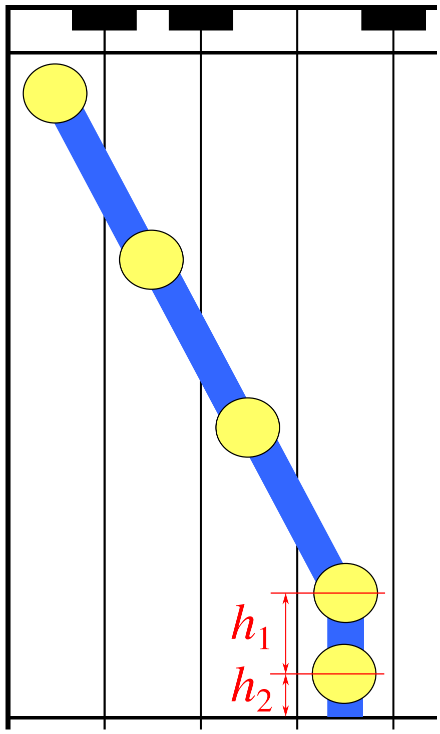


Figure 9. Previous style of VLN score (handmade) for Figure 8.

4.3 New style of VLN

Figure 8 shows an example score in staff notation which includes eighth notes. Figure 9 represents the conventional style of VLN score (handmade) which is equivalent to the score in Figure 8. In this case, in Figure 9, the length of the last eighth note is expressed shorter than the length of the previous one: $h_2 < h_1$.

Therefore we propose a new style of VLN as shown in Figure 10: the first note is put on the bar line. The length of the last eighth note is equal to the previous one: $h_2 = h_1$.

In the next section, we will explain the conversion method for making this style of VLN scores from SMFs.

4.4 Conversion from SMFs to VLN scores

In SMFs, the header chunk and the track chunk begin with a magic number as "MThd" and "MTrk." First, it is necessary to find these bytes in a MIDI file. In the header chunk, a time resolution, which is called "time base," is defined. This shows a capacity to decompose a quarter

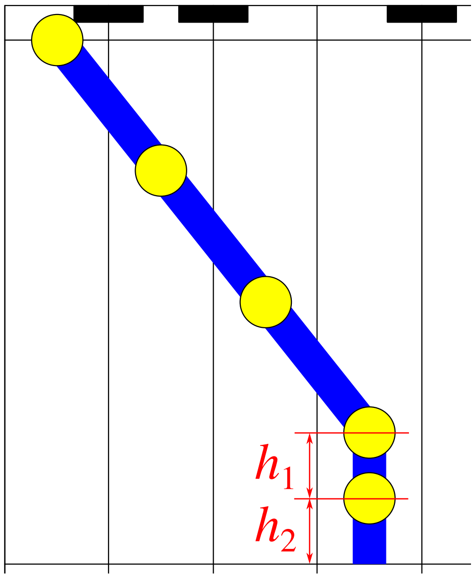


Figure 10. New style of VLN score (automatic converted from SMF) for Figure 8.

note. For example, if a time base is equal to 480, it is possible to express the quarter note as 480 divided lengths. "Delta time" is also described together in all MIDI events in which the MIDI file is represented. It represents the time until the next event is performed. Both "note-on" (a command for turning the sound on) and "note-off" (turning off the sound) are used to represent a note length. For example, in the case that a time length from note-on to note-off is equal to time base, it is equivalent to a quarter note.[*3] If we let S represent a time for note-on, and E be a time for note-off, then D means a time base. The meter will be four-four time, and a piece of music has no anacrusis. In these conditions, a note length l is calculated by Equation (1):

$$l = (E - S) \;/\; (D \times 4), \tag{1}$$

where $D \times 4$ is equal to the whole time length in a musical bar.

A note position P from the beginning in a measure is obtained by Equation (2), and a measure number M of a note is given as Equation (3):

$$P = S \; mod \; (D \times 4), \tag{2}$$

$$M = [S \;/\; (D \times 4)] + 1, \tag{3}$$

where "*mod*" means the remaining operations, "[ ]" indicates the floor function, and the multiplier "4" is equal to the denominator of the musical time. By using these three equations, performance data of a MIDI file are converted to data sequences which have only note length, note position, and measure number. Figure 11 shows l, P, and M.

[*3]Ref. [6] describes formalisms of duration-onset of notes which reminds to performance theory.

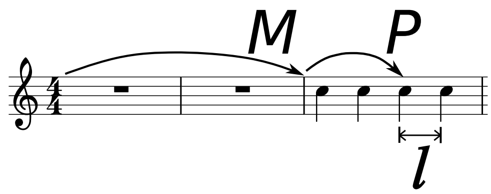


Figure 11. Measure number M, note position P, and note length (duration) l.

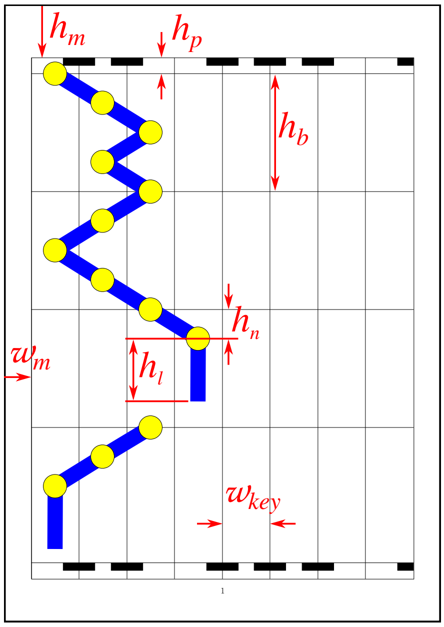


Figure 12. Parameters which are used for calculating y- and x-coordinates of node.

These parameters are used to indicate the vertical position y_{node} of the center of a node in a VLN score;

$$y_{node} = h_m + h_p + h_b \; M + h_n, \tag{4}$$

where h_m, h_p, and h_b shows the height of the top margin, of the piano area, and of musical bar in the VLN score, and h_n corresponds to the position of the node is the musical bar (see Figure 12):

$$h_n = h_b \; P. \tag{5}$$

Note that P is a common fraction. h_l shows the note length (in a VLN score) which is given as Equation (6):

$$h_l = l \; h_b. \tag{6}$$

The horizontal position of the node is calculated easily because SMF includes pitch information clearly. Let n_{lowest} mean the note number of the lowest pitch in the VLN score. This note number corresponds to a pitch v_{lowest} in Table 1 which is the lowest pitch in the VLN score. Let n_{node} represent the note number of the node, x_{node} which is x-coordinates of the center of the node is

p_{lowest}	v_{lowest}
C, D, E	C
F, G, A, H	F

Table 1. Lowest pitch in VLN score. p_{lowest} means lowest pitch in music piece, and v_{lowest} shows the lowest pitch in VLN score.

p_{range}	$v_{highest}$
within 1 octave	1 octave higher of lowest pitch
over 1 octave	highest pitch

Table 2. Highest pitch in VLN score. p_{range} means pitch range in music piece, and $v_{highest}$ shows highest pitch in VLN score.

given as Equation (7):

$$x_{node} = w_m + \frac{w_{key}}{2} + (n_{node} - n_{lowest})\frac{w_{key}}{2}, \quad (7)$$

where w_m shows the width of the left margin in the VLN score, and w_{key} means the key width on the VLN score. The reason why w_{key} is divided by 2 is that the unit of x_{node} is semitone.

The highest pitch in VLN score is obtained from Table 2. For example, in Figure 12, the lowest pitch C4 is assigned to v_{lowest}. Therefore n_{lowest} is equal to 64 which is MIDI note number of C4. The highest pitch is within the 1 octave from n_{lowest} (C4). Thus C5 is substituted into $v_{highest}$.

5. AUTOMATIC DECISION OF PIANO FINGERING FOR BEGINNERS

As shown in the previous section, VLN scores can be made from SMFs automatically, however, it is necessary to put a finger number into each node. VLN scores have finger numbers which are very important to pianist. On the other hand, it is not easy to decide the piano fingering. Hence, we have studied automatic decision of it.

Models and algorithms for decisions deciding appropriate piano fingerings have been studied previously [7, 8, 9, 10, 11]. To enable the adaptation of fingerings for beginners, we present a method based on the hidden Markov model (HMM) [10].

Piano fingering for one hand, say, the right hand, is indicated by associating a finger number $f_n = 1, \ldots, 5$ (1 = thumb, 2 = the index finger, ..., 5 = the little finger) to each note p_n in a score,[*4] where $n = 1, \ldots, N$ indexes notes in the score and N is the number of notes. We consider the probability of a fingering sequence $f_{1:N} = (f_n)_{n=1}^{N}$ given a score, or a pitch sequence, $p_{1:N} = (p_n)_{n=1}^{N}$, which is written as $P(f_{1:N}|p_{1:N})$. As explained below, an algorithm for fingering decision can be obtained by estimating the most probable candidate $\hat{f}_{1:N} = \underset{f_{1:N}}{\operatorname{argmax}} P(f_{1:N}|p_{1:N})$. The fingering of a particular note is more influenced by neighboring notes than notes that are far away in score position. Dependence between adjacent notes is most important, and it can be incorporated within a Markov model. It also has advantages in efficiency in maximizing probability and setting model parameters. Although the probability of fingering may depend on inter-onset intervals between notes, the dependence is not considered here for simplicity.

[*4] We do not consider the so-called finger substitution in this paper.

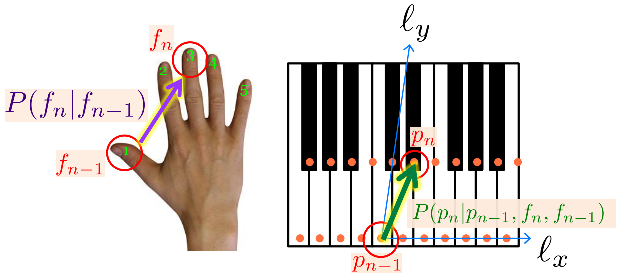


Figure 13. Schematic illustration of the piano fingering model based on HMM.

Supposing that notes in a score are generated by finger movements and the resulting performed pitches, their probability is represented by the probability that one finger would be used after another finger $P(f_n|f_{n-1})$, and the probability that a pitch would result from two consecutively used fingers (Figure 13). The former is called the transition probability, and the latter output probability. The output probability of pitch depends on the previous pitch in addition to the corresponding used fingers, and it is described with a conditional probability $P(p_n|p_{n-1}, f_{n-1}, f_n)$. In terms of these probabilities, the probability of notes and fingerings is given as

$$P(p_{1:N}, f_{1:N}) = \prod_{n=1}^{N} P(p_n|p_{n-1}, f_{n-1}, f_n)P(f_n|f_{n-1}), \quad (8)$$

where the initial probabilities are written as $P(f_1|f_0) \equiv P(f_1)$ and $P(p_1|p_0, f_0, f_1) \equiv P(p_1|f_1)$. The probability $P(f_{1:N}|p_{1:N})$ can also be given accordingly.

To train the model efficiently, we assume some reasonable constraints on the parameters. First we assume that the probability depends on pitches only through their geometrical positions on the keyboard which is represented as a two-dimensional lattice (Figure 13). We also assume the translational symmetry in the x-direction and the time inversion symmetry for the output probability. If the coordinate on the keyboard is written as $\boldsymbol{\ell}(p) = (\ell_x(p), \ell_y(p))$, the assumptions mean that the output probability has a form $P(p'|p, f, f') = F(\ell_x(p') - \ell_x(p), \ell_y(p') - \ell_y(p); f, f')$, and it satisfies $F(\ell_x(p') - \ell_x(p), \ell_y(p') - \ell_y(p); f, f') = F(\ell_x(p) - \ell_x(p'), \ell_y(p) - \ell_y(p'); f', f)$. A model for each hand can be obtained in this way, and is written as $F_\eta(\ell_x(p') - \ell_x(p), \ell_y(p') - \ell_y(p); f, f')$ where η shows left and right hand respectively, and each model exists independent. It is further assumed that these probabilities are related by reflection in the x-direction, which yields $F_L(\ell_x(p') - \ell_x(p), \ell_y(p') - \ell_y(p); f, f') = F_R(\ell_x(p') - \ell_x(p), \ell_y(p') - \ell_y(p); f, f')$. The present model can be extended to be applied to pas-

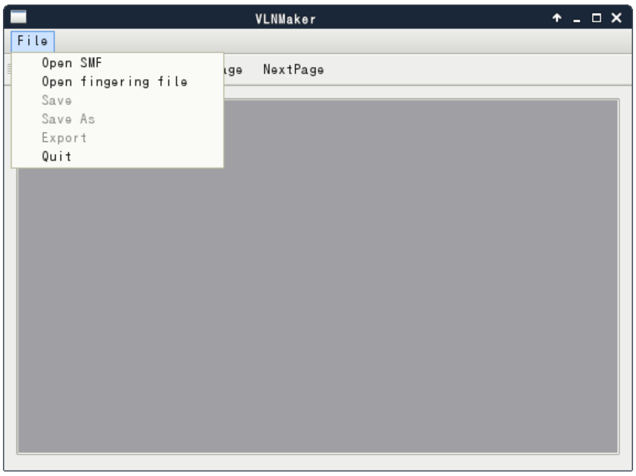


Figure 14. Drop-down menu of “File” on VLNMaker.

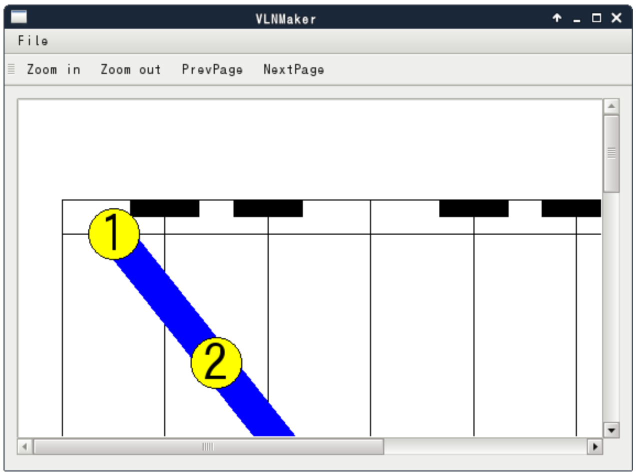


Figure 15. Window state after loaded SMF and piano fingering file.

sages with chords, by converting a polyphonic passage to a monophonic passage by virtually arpeggiating the chords [9]. Here, notes in a chord are ordered from low pitch to high pitch.

To find the optimal fingering for a given piano score using the model, we need to maximize the probability $P(f_{1:N}|p_{1:N})$. This can be computationally efficiently solved with a dynamic programming called Viterbi algorithm [12]. An extension of the above model for both hands is discussed in Ref. [13]. With this extension, it is possible to simultaneously estimate the optimal fingering for both hands from a MIDI file in which notes for the left- and right-hand parts are not separated.

The parameter values for the transition and output probabilities have been obtained in a previous study [13]. Because the used dataset consisted of fingerings for experienced piano players, the obtained fingerings were not fully appropriate for the beginners. For example, using different fingers for pressing successive identical keys is common for the experienced players, but it is not easy to perform for the beginners. To solve this problem, we adapted the trained model parameters to increase the probabilities of self transition for using identical fingers for successive notes.

6. IMPLEMENTATION

We developed a conversion software from SMFs to VLN scores, and we named it “VLNMaker”. We use “Qt” which is a cross-platform programming environment for graphical user interface (GUI). Qt works on Windows, Mac OS X, and Linux. Moreover, it can make an executable file for each OS by using C++ compiler respectively from same source code.

Figure 14 shows drop-down menu of “File” on VLNMaker: “Open score file” to load SMF, and “Open fingering file” to read piano fingering information, and “export” to output PDF file.[*5] After loading SMF and piano fingering information, user can choose “zoom in” and “zoom out” for changing scale of view, and “PrevPage” and “NextPage” for moving previous and next page.

[*5] “Save” and “Save as” have not implemented yet. These menus will be used to save the modified piano fingering by hand. The interactive hand modification function of piano fingering also has not implemented yet.

Subject No.	EPI	reading staff N.	reading VLN	play of the piano	play by using VLN
1	none	C	A	C	A
2	none	C	A	C	A
3	none	C	A	C	B
4	none	C	A	C	B
5	Tb	C	B	C	B
6	Drums	C	B	C	B
7	Gt	B	A	C	B
8	E.Gt	B	A	C	A
9	Cla	B	A	B	A
10	Gt	B	B	B	B
11	Euph	B	B	B	A
12	Piano	A	A	B	B
13	A.Sax	A	B	C	B

Table 3. An inquiry result of beginners’ piano class at Nat. Inst. Tech., Kisarazu College (A: excellent, B: good, C: poor). EPI means experience of playing instrument.

7. EXPERIMENTAL RESULTS

7.1 Inquiry of beginners’ piano class at NITKC

Table 3 shows a result of inquiry of beginners’ piano class at NITKC (see Section 3.3). 13 students who were interested in playing the piano volunteered for this class which took 90 minutes.

All the subjects could read VLN scores easier than or equal to staff notation scores except one of them. The subject 13 is used to reading staff notation scores and usually plays alto saxophone, and this is the first time seeing VLN scores. Therefore, it seems that prior knowledge of traditional staff notation caused interference in reading VLN scores for this subject. Although most of the subjects have

Test 1

Test 2

Test 3

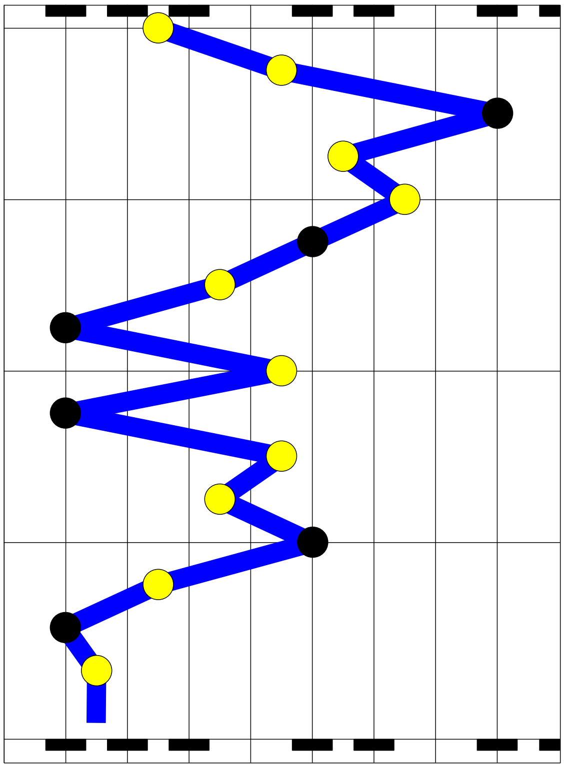
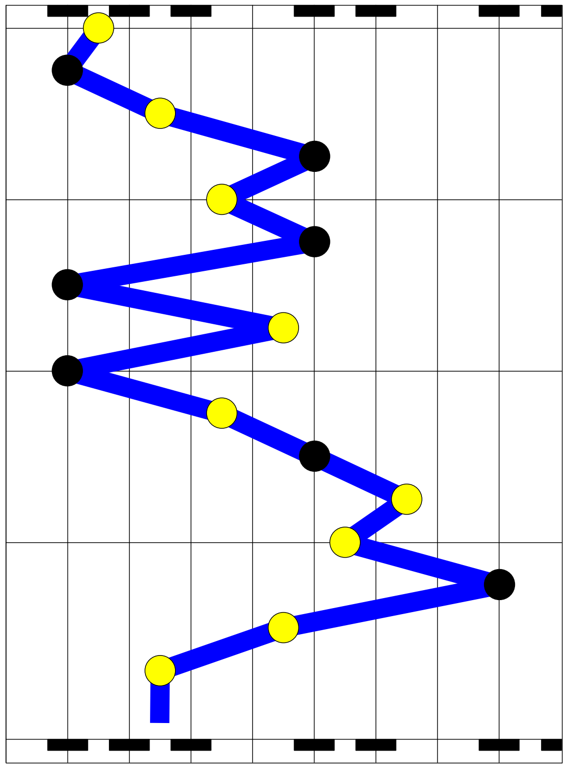


Figure 16. Scores used reading test.

Test 4

Test 5

Test 6



Test 7

Figure 17. Scores used reading test (continued).

not took any regular piano lesson, all the subjects could play the piano well in the class.

These results suggest that VLN scores provide a greater chance of success when introducing the piano to beginners.

7.2 Comparison of performance with VLN scores and staff notation scores

In order to examine the readability of VLN scores, we compared with piano performances between in case of using VLN scores and using staff notation scores. We used example scores as shown in Figure 16 and Figure 17. The score of Test 3 and Test 6 does not contain finger number because we expected that subject just concentrates on pressing correct key. Therefore all the subjects pushed the key only with index finger. In the score of Test 4 and Test 5, each note has an accidental respectively. Note that the score of Test 3 and Test 7 are the same music piece. Subjects were NITKC students. Among them, each member of group A was not used to read staff notation score, and group B was used to. We taught them the pitch of first note of each score and instructed them to continue playing the piano even if the subject noticed mistake by oneself. The playing tempo was free.

Table 4 shows the result of the number of miss-key hitting. Most subjects A_i made mistakes in the case of using staff notation score. On the other hand, subjects B_i played completely without errors. All subjects performed without or with a few mistakes in the case of using VLN scores. Especially, although the score of Test 3 and Test 7 are the same music piece, each number of mistakes for Test 3 is less than that for Test 7 for subjects A_i.

Table 5 shows the results of playing duration. The durations in the case of using VLN scores are less or equal to the duration in the case of using staff notation scores for most subjects A_i. Although subject A_{10} finished Test 7 faster than Test 3, the number of mistakes in Test 7 is larger than in Test 3. For subject B_i, in contrast, the duration in the case of using VLN score is greater or equal than using staff notation score.

From the above results, we consider that the readability of VLN scores is high for music beginner players. However, it is not necessarily the case for people who are accustomed to read staff notation score. The most important thing is to be able to play the piano for music beginner, namely first consideration is that subject experiences success performances. Therefore, at first, piano beginners may not recognize pitch name clearly, and they only have to under-

Subject No.	Scores / Number of miss-key hitting						
	1	2	3	4	5	6	7
	G	F	VLN	G	F	VLN	G
A_1	8	2	0	6	5	3	1
A_2	6	6	0	11	6	0	9
A_3	9	8	0	7	3	1	8
A_4	10	9	0	13	8	0	8
A_5	8	8	0	9	3	0	8
A_6	6	6	0	1	0	0	6
A_7	8	8	0	3	3	0	8
A_8	6	8	0	9	7	0	6
A_9	6	0	0	1	1	0	6
A_{10}	1	0	0	1	0	0	7
B_1	0	0	0	0	0	0	0
B_2	0	0	0	0	0	0	0

Table 4. The number of miss-key hitting. Subjects A_i are not used to read staff notation score, subjects B_i are used to. G and F mean staff notation score in G clef and F clef, and VLN signifies VLN score. Note that score 3 and score 7 are same music piece.

Subject No.	Scores / Duration [sec]						
	1	2	3	4	5	6	7
	G	F	VLN	G	F	VLN	G
A_1	140	96	40	144	68	52	64
A_2	88	76	68	80	76	44	84
A_3	72	68	48	72	68	32	52
A_4	140	88	88	116	64	76	88
A_5	176	76	44	108	80	36	72
A_6	64	80	48	52	60	52	60
A_7	64	52	36	80	76	40	88
A_8	64	64	48	60	52	36	48
A_9	40	48	32	64	52	28	52
A_{10}	84	84	72	82	60	52	40
B_1	40	52	44	44	40	44	32
B_2	20	16	28	20	20	28	20

Table 5. Playing duration. Subjects A_i are not used to read staff notation score, subjects B_i are used to. G and F mean staff notation score in G clef and F clef, and VLN signifies VLN score. Note that score 3 and score 7 are same music piece.

stand the position of the key which will be pressed. Of course, understanding pitch name is also important, thus we will discuss in Section 8.2 and Section 8.3.

7.3 Production of VLN scores for beginner players and advanced players, and their influence on performances

Figure 18 shows an example of VLN score: the beginning of "March" from "The Nutcracker Suite op.71a" by Peter Ilyich Tchaikovsky. Finger numbers in Figure 19 are for beginners, and the VLN score is produced by VLNMaker. Finger numbers in Figure 20 are for advanced player, and the numbers are given by a professional piano player.[*6]

We examined differences of ease of playing in the case of using VLN scores for beginners versus advanced players. The subjects were students who belonged to NITKC, and their age was from 19 to 20 years old. First, we instructed how to read VLN score to subjects. Second, we asked them to play the song "tulip" to be used to read a VLN score. In this case, if the subjects made mistakes in their piano playing such as missed-key strokes and/or wrong fingering, we ignored those errors. Third, they played the only 2 bars of the beginning of "March" twice by changing the fingering. In this case, we asked them to repeat their practicing of the piece until they could play completely without errors.

Table 6 shows results of inquiry about piano playing using VLN scores. None of the subjects had previously practiced playing the piano in regular lesson. The results show that they could play easily when they used a VLN score for beginners versus one designed for an advanced player.

[*6]VLNMaker can also load a text file which contains piano fingering information which is made by hand. In this case, we prioritized ease of understanding, hence we omitted rests in the VLN scores.

8. DISCUSSION

8.1 Score arrangement

We consider that it is necessary to establish an arrangement method. Although the vertical line notation can show music faithfully, it is difficult to play complex chords and phrases, a sequence of very short notes, or a large jump of pitch for beginners. We will solve these problems by reducing the number of notes, simplifying rhythms, and adjusting pitches to match player's skill while keeping the atmosphere of the original music as much as possible.

8.2 Expansion of VLN

We plan to expand the vertical line notation. A characteristic of the vertical line notation is simplicity compared with staff notation. On the other hand, we are considering giving it a more functional representation. Figure 21 and Figure 22 show examples of musical scores ("For Elise" by Ludwig van Beethoven) in expanded vertical line notation. Both figures contain the left hand part, which is arranged, and repeat marks shown as a green line and dots on the upper portion in Figure 21 and on the lower portion in Figure 22 respectively. Moreover, these VLN scores contain large jump of pitch relatively, in these part, same finger does not always use. Another examples are shown in Figure 23 and Figure 24. These figures include chords which is shown as connected two nodes with a horizontal broken line respectively, and left hand part as orange nodes. Our developed software will be able to deal with information of these kinds.

Furthermore, there is room for improvement for the use of color. For example, the background of the keys of C and F are expressed using pale red and green.

In addition, it is important to express a length of each note. Currently, the vertical line notation shows the length of the note by the vertical distance between nodes. Al-

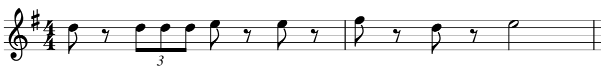


Figure 18. Staff notation score at the beginning of "March" by Tchaikovsky.

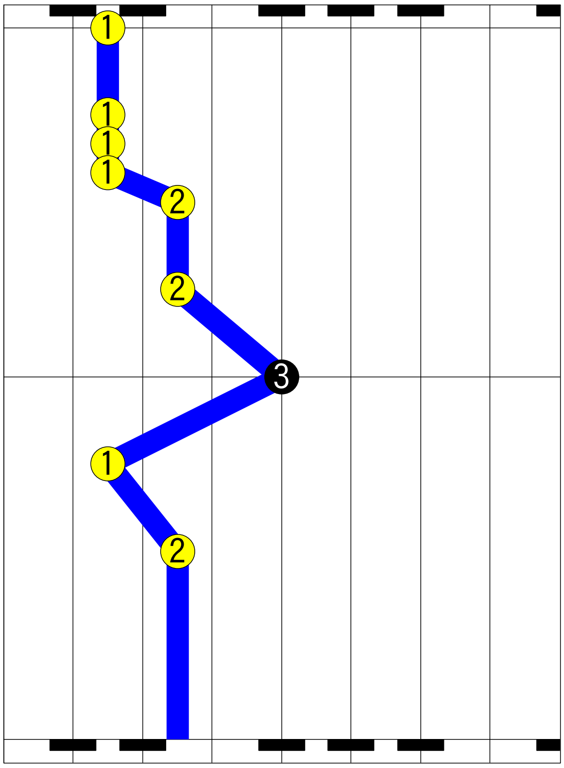


Figure 19. A converted VLN score from SMF for beginners of "March" from "The Nutcracker Suite" by Tchaikovsky.

though it is simple, the player may not understand the length of the note immediately. Therefore, for example, we are considering showing each node by a rectangle instead of a circle, and the height of the rectangle would indicate the length of the note. Furthermore, it may be useful to use different colors for various note lengths.

However we should pay attention to complexity of notation. Although complex notation scores have various and detailed information of music, such scores cause confusion for beginner player. Namely, readability and complexity are a trade-off relationship.

8.3 Transition from VLN to staff notation

At senior keyboard class in Showa University of Music, some of the early joined members tried to play the piano while putting VLN scores in a landscape orientation. It shows as same as staff notation: vertical direction represents the pitch of notes and horizontal direction expresses time flow.

Currently, most of the members proceed to using staff notation scores which are chosen as liking music pieces

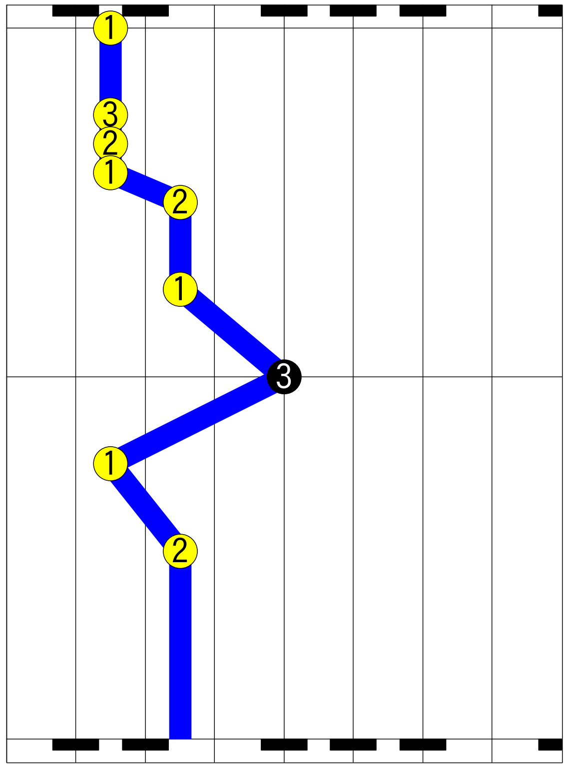


Figure 20. A converted result of VLN score of "March" for advanced players.

subject No.	reading VLN	playing by using VLN		
		T	$\mathrm{M_{bgn}}$	$\mathrm{M_{adv}}$
1	B	B	B	C
2	B	A	A	B
3	B	A	B	B
4	B	B	A	B
5	B	B	B	C
6	B	B	C	C
7	B	B	B	C
8	A	A	A	C
9	A	A	A	C
10	B	B	A	C

Table 6. Results of inquiry about piano playing using VLN scores (A: excellent, B: good, C: poor) and situation of play. Each T, $\mathrm{M_{bgn}}$ and $\mathrm{M_{adv}}$ shows use of a VLN score of the song "Tulip," "March" for beginners and "March" for advanced players. All the subjects had not formerly practiced playing the piano in regular lesson.

themselves. In fact, many piano score books in staff notation are sold, and this is one of advantages of staff notation. It seems that the members are used to play and have confidence in playing the piano gradually, thus they are going to be more aggressive. This case is a success instance of introduction of playing the piano, and is also "graduation" of VLN scores.

We will try to construct a more systematic learning method for transition from VLN score to staff notation

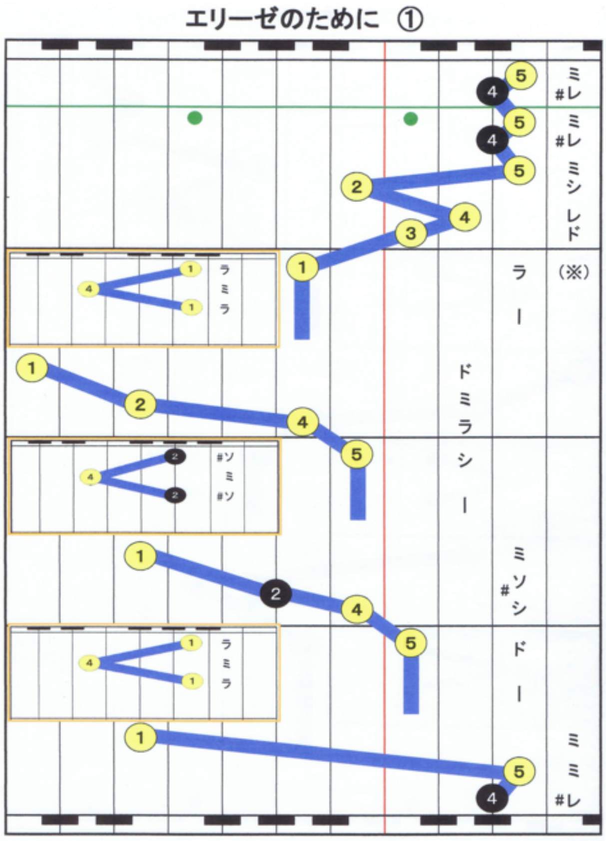


Figure 21. VLN score of the first page of "For Elise" by Beethoven (handmade).

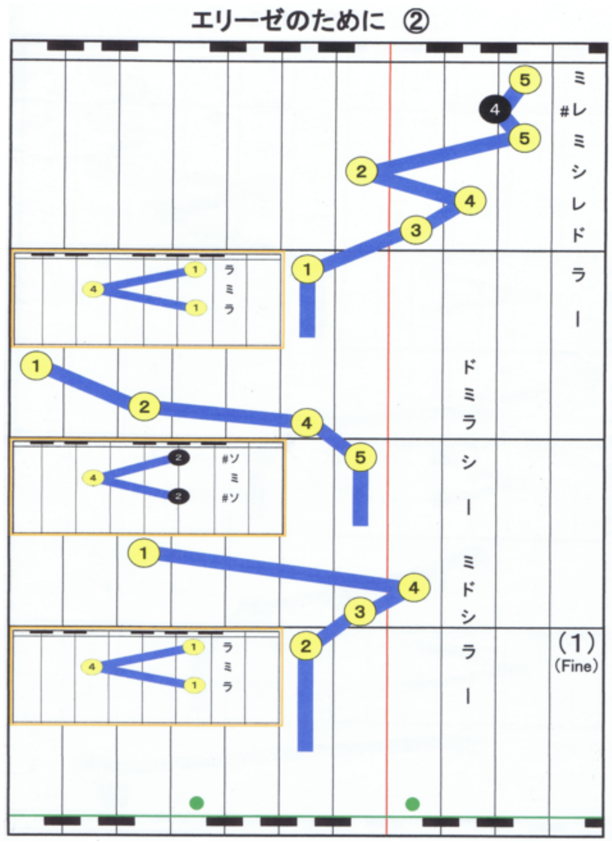


Figure 22. VLN score of the second page of "For Elise" (handmade).

score: it is necessary to learn the various information in staff notation such as pitch names, rule of accidentals, note lengths, expression marks, etc.

8.4 Fingering check system

We plan to construct a fingering check system which obtains images of the moving state of a piano player's hand and fingers by using a movie camera, specifically, an RGB-D camera such as Microsoft Kinect sensor [14], ASUS Xtion Pro Live [15], Leap Motion [16, 17], etc. Using these device, we can implement non-contact type system. It is important to use "natural input" for constructing user friendly system which does not ideally bring any stress for users. The fingering check system can provide a self-learning material for beginner player, and also automatically estimate the playing skill level of a piano player by analyzing the images. Hence, an automatic conversion system for VLN scores from SMFs will be improved to provide VLN scores with appropriate difficulty of piano fingerings which would correspond to the player's piano skill.

8.5 The spread of VLN

We consider spreading VLN score widely. Now, regular piano lessons with VLN scores have held in limited places yet such as Showa Music University, Heisei Music University, Ooizumi Elementary School, etc. One of the reason is that VLN scores are made by hand. With regard to this problem we believe that our study will solve it. Another one is that practice method is developing. Because the number of piano teacher with VLN score is not enough, it is necessary to teach the learning method using VLN score to teachers rather than students in advance.

In the near future, we will apply VLN scores not only for music education but also rehabilitation, music therapy, etc.

9. CONCLUSIONS

This paper described a conversion method from standard MIDI files to the "vertical line notation" (VLN), and an algorithm of automatic decision of piano fingering for piano beginners. Because VLN scores have been made by hand on Microsoft Excel currently, we developed an automatic conversion system from standard MIDI files to VLN scores. Moreover, we proposed an automatic decision of piano fingering for beginners. We confirmed that fingering for beginners is easier to play than fingering designed for the advanced players.

As future work, we plan to solve several problems described in section 8, and improve both VLN itself, and the automatic conversion system of VLN scores from SMFs.

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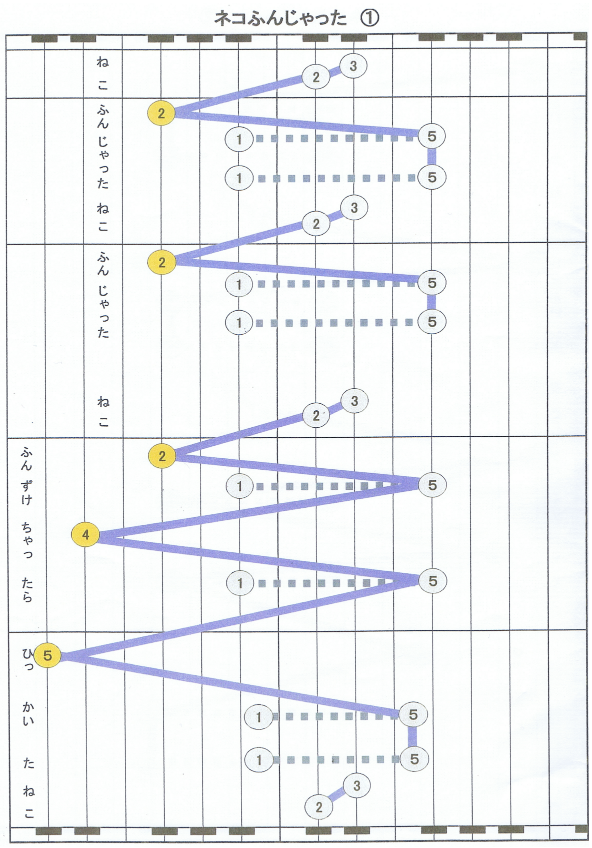

Figure 23. VLN score of first page of "Flea Waltz" (handmade).

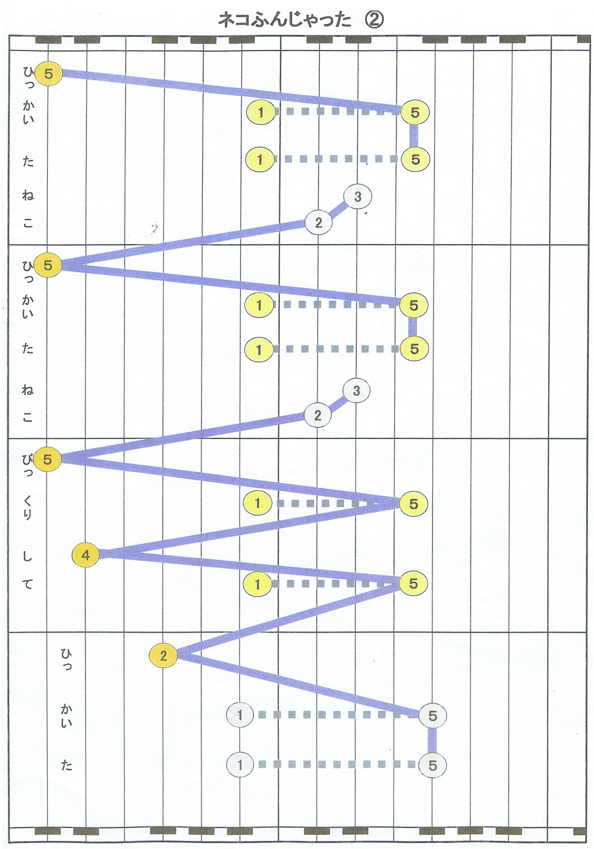

Figure 24. VLN score of second page of "Flea Walz" (handmade).

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