Computer Facilitated Creation in Musical Performance

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Abstract— **Music is one of the most sophisticated as well as one of the most popular arts. Everyone wants to hear new good music. However, the productivity of composing pieces of music is limited. Moreover, people want to enjoy not only listening to but also performing music. However, many difficulties prevent people from actually performing music. We have been working on technologies that enhance human musical creativity. This paper discusses how computer can and should facilitate the creative processes involved in performing music. We describe three attempts made toward this aim: supporting musical divergent thinking, supporting conveyance of musical knowledge, and supporting non-creative musical processes. Based on our experiences in making these attempts, we discuss how and where computers can contribute to the musical creation process.**

Keywords— **Creation in Musical Performance, Computer Support**

I. Introduction

MUSIC is one of the most sophisticated as well as one of the most popular arts. Many people enjoy listening to music, and there is probably nobody who dislikes listening to music. Accordingly, the world surrounding us is always filled with music. We cannot spend even one day without listening to pieces of music in our daily life. Furthermore, people cannot be satisfied with old pieces of music and always desire “new good” pieces of music. To meet this expectation, an enormous number of musical pieces are being constantly composed by many composers. As a result, the consumption rate of pieces of music has recently become dramatically faster. Therefore, increased productivity of music composition is clearly demanded. However, the number of composers who can produce good pieces of music is limited. Moreover, not only the quantity but also the quality of the composed pieces of music by a certain composer is limited.

At the same time, many people are not satisfied with enjoying music passively, i.e., just listening to music. They want to play musical instruments by themselves and create their own music. Therefore, they begin to study and practice musical instruments. However, it is usually difficult for a person to master a musical instrument. To perform a piece of music, he/she must learn the music theory, e.g., how to read/write a score. In addition, he/she must attain sufficient skill to play a musical instrument, e.g., how to blow a trumpet and how to bow and finger a violin. It is difficult to study music by oneself, so aspirants often go to a music school and take some musical lessons. However, this requires a major commitment of time and money. Even if the student has enough time and money, if the rapport between the student and the teacher is not good, it is difficult to achieve good results. These difficulties prevent most people from actively engaging in music study.

Thus, there are two big issues in the contemporary situation of music: how to increase productivity of composition and how to alleviate the difficulties in actively attempting musical performance. To solve these issues, we have been studying facilitating methods and systems for musical creation by using a computer. Currently, we are approaching this study with three strategies: supporting divergent thinking for melody creation, supporting the conveyance of musical knowledge, and supporting non-creative processes in musical performance. This paper describes these three attempts and discusses the possibility of facilitating musical creation by using a computer.

The rest of this paper is organized as follows. Section II describes a divergent thinking support tool for melody creation in jazz improvisation. Section III describes a method to support conveyance of musical knowledge in piano lessons. Section IV describes a jazz improvisation support tool by assisting non-creative processes in musical performance. Section V discusses the possibility of facilitating musical creation by using a computer based on our experiences in working on the three strategies. Section VI concludes the paper.

II. Divergent Thinking Support for Melody Creation

It is generally said that there are two major processes in creative thinking: a divergent thinking process and a convergent thinking process [1]. In the divergent thinking process, people collect from various viewpoints as many idea-pieces as possible that may be related to the issue to be solved. Then, in the convergent thinking process, people clarify the relationships among the collected pieces, compile them, and finally obtain some new idea.

We think the process of musical composition is similar to the process of creative thinking. That is, a composer creates various phrases (pieces of melody), selects some good phrases, compiles them, and finally composes a musical piece. A melody consists of phrases; therefore, in musical composition, creation of good phrases is especially important. In other words, the divergent thinking process, in which various candidates of phrases are generated, plays a very important role in the entire process of music composition. Therefore, we have been studying how to create a support system for the divergent thinking process in mu-

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sical composition. This section describes this system and illustrates how it can support melody creation.

A. *Music-AIDE: a musical divergent thinking support system*

Music-AIDE is a prototype system that visualizes the relationships among the phrases of a musical piece and several musical primitives, which are weighted features extracted from the phrases, as two-dimensional spatial structures. By observing the visualized space, people can find the characteristics of the melody based on the relationships of the phrases. Furthermore, hints on creating novel phrases can be found by analyzing the empty spaces that often appear in the space.

A.1 Musical Primitives

Currently, Music-AIDE can handle only single-note melodies; only the highest note is employed, even if a chord is input. A melody is input to Music-AIDE in MIDI (Musical Instrument Digital Interface) format. It is usually difficult to automatically determine a phrase. Therefore, we divide the entire melody into four-bar units and regard a four-bar unit as a phrase. Conversely, a melody is a sequence of four-bar units, i.e., phrases. Then, from all of the phrase data, the following musical primitives are extracted:

- *Number of notes* Number of notes that are included in the phrase.
- *Average pitch* Average pitch (pitch is represented by MIDI note number) of the phrase with consideration to the duration of each note.
- *Variance of pitch* Variance of pitch of notes that are included in the phrase.
- *Representative length of repetition* The most significant cycle obtained from self-correlation of temporal transition of pitch in the phrase.
- *Power of half-note scale* Integral of power over half-note length obtained by fast fourier transform on the transition of pitch in the phrase.
- *Power of quarter-note scale* Integral of power between half-note length and quarter-note length.
- *Power of eighth-note scale* Integral of power between quarter-note length and eighth-note length.
- *Power of sixteenth-note scale* Integral of power between eighth-note length and sixteenth-note length.
- *Power of under-16th-note scale* Integral of power under 16th-note length.
- *Monochrome chord tone* The I_{st} and V_{th} notes of the currently available note scale [1]. These present a very consonant feeling but lack the feeling of tonality.
- *Colored chord tone* The III_{rd} and VII_{th} notes of the currently available note scale. These present a very consonant feeling as well as the feeling of tonality.
- *Tension note* Notes that are included in the currently available note scale except for the monochrome chord tones and the colored chord tones. These present a floating feeling and/or tension feeling.
- *Out note* Notes that are not included in the currently available note scale. These present a very strong tension feeling.
- *Avoid note* Notes that present the feeling as if the current chord changes to another chord. These notes are included in the currently available note scale and are defined in the Berklee theory [2].

A.2 Visualization of Relationships among Phrases and Musical Primitives

We employed the thought-space structuring method of Sumi et al. [2], in which relations between concepts and elements of concepts are represented by spatially arranging the concepts and elements. For this spatial arranging, they applied the dual scaling method, which is a multi-variant statistical analysis method that provides principal components of given data [3]. When an object set that consists of multiple quantification attributes is given, the dual scaling method represents the relations of the attributes shared among the objects and the co-occurrent relations among the attributes as spatially relative relations. This is done by quantitatively grading the object set and the attribute set. In our research, a phrase corresponds to an object and a musical primitive corresponds to an attribute. As a result, relationships among phrases and musical primitives are represented in a two-dimensional space.

Figure 1 illustrates a very basic sample of this type of space. In this figure, a rectangular icon correponds to a phrase and an elliptical icon corresponds to a musical primitive. The horizontal axis and the vertical axis of the space correspond to the first principal component and the second principal component, respectively. For example, in this figure, phrases P1 and P2 are arranged closely. Generally, the weights of the musical primitives in both of the phrases are similar and thus they are similar phrases. On the other hand, phrases P1 and P3 are separately arranged. Therefore, we can say that these phrases are quite different. As for the musical primitives, primitives p1 and p2, which are closely arranged, have a similar weight in each phrase, while primitives p1 and p3, which are arranged at a distance, have opposite weights. In other words, when p1 is heavily weighted, the weight of p3 is not heavy, and vice versa, in each phrase. Primitive p4 is arranged in the middle of phrase P3 and P4; this indicates that primitive p4 has similar and relatively heavy weight in phrases P3 and P4.

B. *How Music-AIDE Supports Melody Creation*

Figure 2 shows a sample that analyses Miles Davis's improvisation of "Autumn Leaves," featured on Julian Can-

[1] Available note scale is obtained by the analysis of the chord progression based on the Berklee theory. Simply speaking, the notes included in the available note scale are "theoretically correct" notes that are relatively consonant to the current chord. Of course, a performer/composer can also use notes that are not included in the available note scale to create a more complicated melody. Generally, a melody that consists of only available notes becomes monotonous and uninteresting.

[2] The "Berklee theory" is a well-known jazz theory established at the Berklee College of Music based on the 40's Be-Bop style jazz. This theory is the basis of most contemporary popular music.

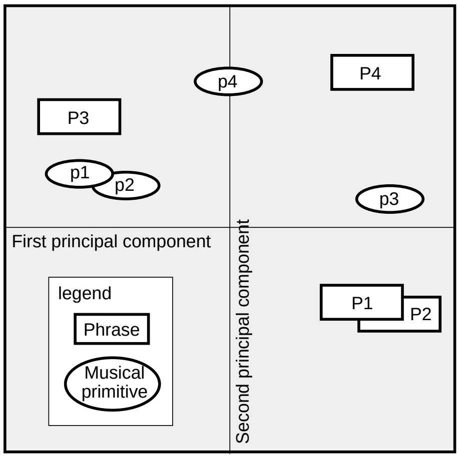

Fig. 1. Basic sample of space visualized by Music-AIDE.

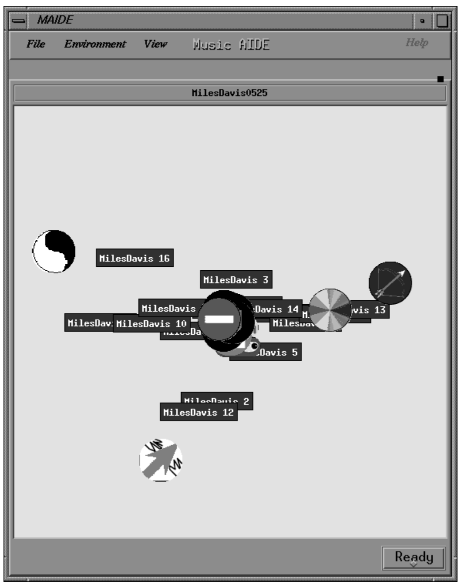

Fig. 2. Spatial structure based on Miles Davis's improvisation in "Autumn Leaves."

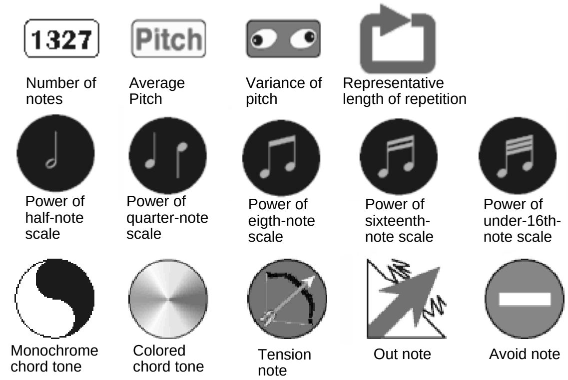

Fig. 3. Icons of musical primitives.

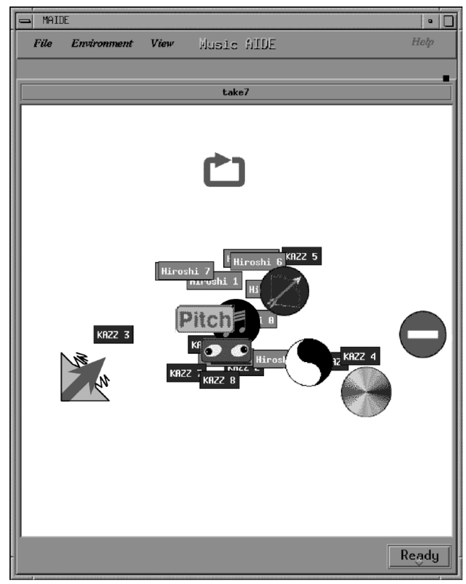

Fig. 4. Spatial structure after 2-chorus performance by one of the authors.

nonball Adderley's very famous album "Somethin' Else." There are 16 phrases (64 bars) arranged in the space. Each phrase is represented as a rectangular icon that indicates the performer's name (i.e., Miles Davis) and the sequence number of the phrase. The musical primitives are represented as various picture icons. The correspondence of the icons and the musical primitives is shown in Fig. 3.

From this figure, we can easily see that the three musical primitives, i.e., monochrome chord tone, tension note, and colored chord tone, mainly contribute to the first principal component, while out note and monochrome chord tone contribute to the second principal component. We showed this result to a jazz guitar player. He was interested in the relationship between monochrome chord tone and colored chord tone. That is, the icons of monochrome chord tone and colored chord tone are arranged on opposite sides of the horizontal axis. This means that Miles exclusively used monochrome chord tone and colored chord tone. The guitarist had never heard of such a way of improvising, and immediately tried this newly found improvisation technique. As a result, he found that "cool" phrases can be created this way. This is a typical example of how Music-AIDE can support the discovery of unknown rules for creating new melodies.

Figure 4 shows another sample that analyses one of the author's own improvisational performances. The performed piece of music is "All the things you are," a standard jazz number. This space includes 18 phrases (72 bars) that were obtained from two choruses. From this figure, we can see that avoid note and out note are significant for the first principal component. This means that he used rather many theoretically non-correct notes in his performance. In addition, monochrome chord tone and colored chord tone often co-occurred in a phrase, different from the example of Miles Davis. Thus, we can grasp the features of our own performance from an "objective viewpoint" to find problems.

Furthermore, we can find some new directions to create novel melodies by considering how we can create a melody by arranging it in the empty regions where no phrase icons are arranged in the space. For example, we can find three empty regions in Fig. 4: upper-left region, upper-right region, and lower region. To create a phrase that could be arranged in the upper-right empty region, we can see that the weight of avoid note and the representative length of repetition should be heavy in such a phrase. Thus, this space indicates ways of melody-creation that have not yet been attempted. This allows users to notice their own fixed ideas and break through them.

III. Supporting Musical Knowledge Conveyance

As a basis for musical creation, the accumulated musical knowledge of predecessors is indispensable. Therefore, one who wants to create something in the musical domain must first learn musical knowledge. For this purpose, the pupil reads text books in music and/or studies under music teachers. However, most musical knowledge exists as "tacit knowledge"; although the musician can understand that she/he has this knowledge, she/he cannot describe or explain the knowledge. Furthermore, the tacit knowledge is usually more important than the explicit knowledge in the musical domain. Therefore, the pupil must learn the tacit knowledge, but this is usually very difficult, requiring not only reading books but also studying under experienced music teachers.

We are currently working on a system to support knowledge conveyance from a teacher to a pupil in musical instrument lessons. As mentioned above, most musical knowledge is tacit knowledge. Therefore, it is impossible to support knowledge conveyance by, for instance, directly representing or describing knowledge. Accordingly, we are employing an indirect way to support musical knowledge conveyance: indicating how far imitation of the teacher's performance is achieved by the pupil. This method is based on the straightforward idea that the degree of the achievement of knowledge conveyance is reflected in the similarity of the tearcher's and the pupil's performances. Therefore, we think we can show the teacher and the pupil whether knowledge conveyance is successfully achieved by indicating the degree of similarity between their performances. The following sub-section describes a method to indicate the similarity of performances by the teacher and the pupil and shows through piano lesson experiments how the method can support knowledge conveyance and cultivation of creative performances.

A. Analysis of Knowledge Conveyance in Piano Lessons

A piano lesson is a process where a teacher cultivates an individual pupil's creativity in performance. Generally, there are two stages in the course of piano lessons: an imitation stage when the teacher simply instills her/his ways of performance into the pupil and a creation stage when the pupil develops his/her own new expressions based on the instilled ways. Both stages are indispensable[4]. Ideally, the teacher opportunely decides when a certain pupil should advance to the creation stage based on careful observations of the pupil's progress and personality.

In reality, however, it is usually difficult to precisely determine the timing for switching between these two stages. We think one of the main reasons for this difficulty is the fact that both/either the teacher and/or the pupil are/is apt to be satisfied with merely imitating the teacher's way of performance. For instance, even if the pupil wants to progress to the creation stage, the teacher might continue to only instill the teacher's ways of performance. Thus, the teacher prevents the pupil from advancing to the creation stage and may inhibit the pupil's abilities. On the other hand, if a pupil is satisfied with mere imitation, it is difficult for the lesson to progress to the creation stage even if the teacher encourages the pupil to develop her/his own expressions. As a result, the lesson remains indefinitely in the imitation stage. It is assumed that young and inexperienced teachers in particular tend to fall into such practices.

Therefore, we have been studying a method to reveal the current status of a piano lesson to make both the teacher and the pupil aware of which stage they are in, or in other words, how far the teacher's knowledge has been conveyed to the pupil. For this purpose, we conducted piano lesson experiments with two subjects as pupils by two different teaching ways and gathered the performance data, subjective evaluation of the performances, and impressions of the lessons.

B. Piano Lesson Experiments

B.1 Procedure of Experiments

A course consists of five private piano lessons. Each lesson is 40 minutes, and the course is held for three weeks. The selected set piece is the intermediate-level "Moderato cantabile" part of "Fantaisie-Impromptu Op. 66" by F. Chopin, which is a popular, structural and emotional piece. The teacher is C. Ooshima, who is one of the authors. About one month after a course finishes, a piano recital is held where the pupil performs the set piece three times without any instructions from the teacher. So far, we have employed two subjects (pupils A and B). They are female students at our graduate school who started playing the piano in their infancy. Pupil A, in particular, formerly applied to a music university. We let them individually practice the set piece to play without miss-touches before starting the course.

We altered the training conditions of the courses for the two pupils. The teacher aimed to instill in them her interpretation of this piece first. Therefore, the teacher gave both of them analytical instructions on the set piece. However, the teacher gave such detailed instructions to pupil A only in the first three lessons and then let pupil A perform almost freely in the remaining two lessons, while she gave detailed instructions to pupil B throughout the course.

We used a YAMAHA Silent Grand Piano C5 that outputs MIDI (Musical Instrument Digital Interface) note-on/off and pedal control messages. Therefore, we could record the performances with VCR and DAT equipment as well as by computer (SGI Indy workstation) in MIDI data. The teacher let the pupil perform the entire piece at the beginning and the end of each lesson and recorded the performances in these three ways (two more performances of the entire piece were performed in the middle of the first lesson, and they were also recorded in the same three ways). Additionally, after each piano lesson, we let the pupil write down her impressions of the instructions and of her performances. The teacher did not read them until the entire course was finished.

After a course was completed, we gathered subjective evaluations by the pupil and the teacher of the pupil's performances and the teacher's performances. To do this, they listened to the recorded pupil's performances (the first and last performances of each lesson) and the teacher's performance recorded separately. They listened to each performance three times, that is, a total of 33 performances. The sequence of performances was randomly shuffled. Therefore, they could not know whose and which performance they were listening to. They graded each performance on a scale of ten (1: poor to 10: excellent) and commented on each performance.

B.2 Data analysis

First, the performance data in MIDI format is divided into the performance data of right hand and the performance data of left hand. From the performance data of each hand, we calculated quarter-note-level velocity [3]. Each MIDI note-on message includes a velocity value. The quarter-note-level velocity was obtained by calculating the average of the velocity values of notes included in the interval of a quarter note. In this paper, hereafter, we simply call quarter-note-level velocity "velocity."

The velocities were normalized as follows:

$$\tilde{v_i}^{(n)} = \frac{v_i^{(n)} - \bar{v}^{(n)}}{s^{(n)}}, \tag{1}$$

where $\tilde{v_i}^{(n)}$ is the normalized velocity of the i-th quarter note from the first of the n-th performance, $v_i^{(n)}$ is raw velocity data of the i-th quarter note of the n-th performance, $\bar{v}^{(n)}$ is the average velocity of the n-th performance, and $s^{(n)}$ is standard deviation. In this paper, "velocity" means normalized velocity unless stated otherwise. A performance of a pupil and a performance of the teacher are compared as follows:

$$d^{(n)} = \sqrt{\frac{\sum_i^N (v_i^{(t)} - v_i^{(s,n)})^2}{N}}, \tag{2}$$

where $d^{(n)}$ is the total difference between the n-th performance of the pupil and the performance of the teacher, $v_i^{(t)}$ is the normalized velocity of the i-th quarter note from the first in the performance of teacher, $v_i^{(s,n)}$ is the normalized velocity of the i-th quarter note from the first in the n-th performance of pupil s, and N is the total number of quarter notes in the score.

We calculated $d^{(n)}$ values by using only the data of the teacher's three performances to estimate the minimum value of $d^{(n)}$. By calculating all combinations of two of the three recorded performances of the entire set piece, the following results were obtained: $d_{velocity}^{(n)} = 0.37 \sim 0.48$. Reproducibility of the teacher's performances was very high according to those who listened to them. Therefore, unavoidable human fluctuation caused these values, and it can be assumed that the access limit is around $d_{velocity}^{(n)} = 0.5$ for the entire piece. This level can be used as an index of the end of the imitation stage.

C. *Results of Piano Lesson Experiments*

C.1 Comparison in Entire Set Piece Level

Figures 5 and 6 show the velocity difference of the entire piece between the pupils' performances and the teacher's performance at each lesson. The results of subjective evaluation are also shown in these figures. Here, the x-axis corresponds to the performance, e.g., 1.1 means the first performance of the first lesson, 3.L means the last performance of the third lesson, and M.2 means the 2nd lesson in the recital held one month after the end of the course. The left y-axis corresponds to the value of velocity difference obtained by equation (2), and the right y-axis corresponds to the average grade of subjective evaluation. The differences by the left hand and by the right hand are separately illustrated in both figures as "left" and "right," respectively.

In Figure 5, it is evident that the velocity difference became smaller toward the third lesson and larger toward the last lesson. Interestingly, we can see that the transition of subjective evaluation by pupil A strongly correlated to the transition of the velocity difference. Namely, the smaller the difference became, the lower the subjective evaluation became, and vice versa. On the other hand, in Fig. 6, the velocity difference between pupil B and the teacher became almost monotonically smaller toward the last lesson. Furthermore, the smaller the difference became, the higher the subjective evaluation of pupil B became.

Thus, the relationship between the difference and the subjective evaluation showed opposite tendencies for pupils A and B. These results probably derive from the difference between the two pupils in their ideas of what a "good performance" is, or in other words, the difference of their personalities. This assumption is supported by the pupils' comments in the subjective evaluation.

C.2 Comparison at Quarter-Note Level

We further compared each of the pupils' performance with the teacher's performance at phrase-level: the set piece consists of six phrases as shown in Table III-C.2. As a result, we found that there were several performances of certain phrases that have almost the same difference values but are different when listened to. In this section, we

[3] We analyzed not only the velocity data but also the IOI (inter-onset interval time) data, but we omitted the data and analysis based on the IOI data in this paper. For more detail analysis of these piano lesson experiments including the analysis on the IOI data, please refer to our literature [5].

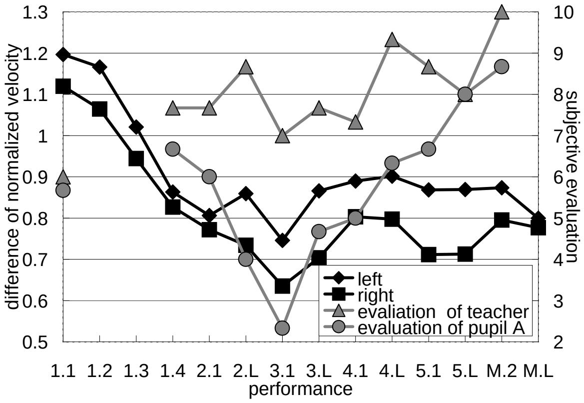

Fig. 5. Transition of total difference of velocity between pupil A and teacher

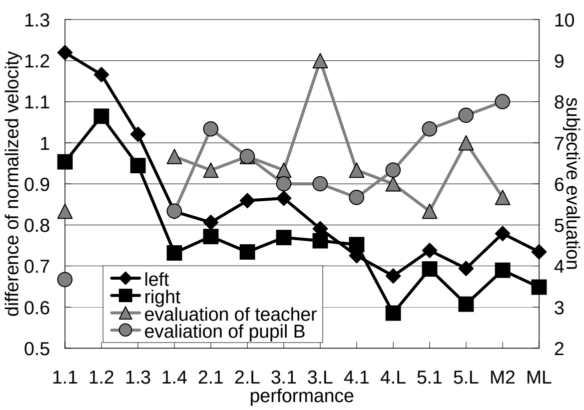

Fig. 6. Transition of total difference of velocity between pupil B and teacher

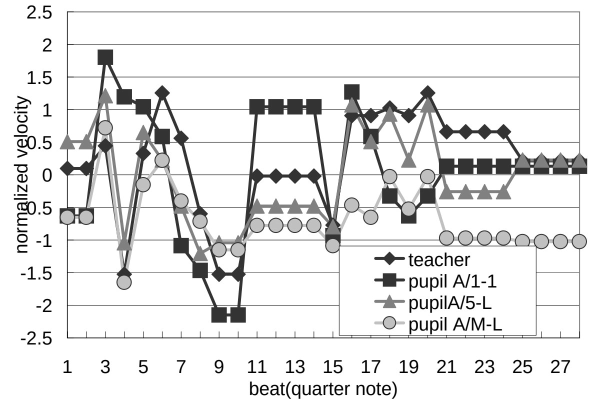

Fig. 7. Velocity of each quarter note in phrase 1st A by pupil A and teacher

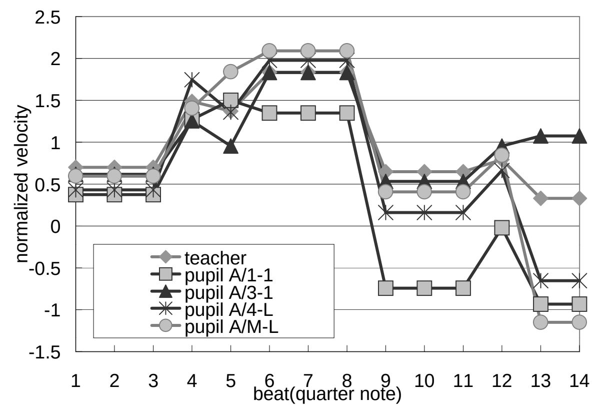

Fig. 8. Velocity of each quarter note in phrase 2nd B by pupil A and teacher

examine quarter-note-level transition of such phrases.

Figure 7 shows quarter-note-level velocity transition of three performances of phrase 1st A by pupil A: the first performance of the first lesson (1-1), the last performance of the fifth lesson (5-L), and the last performance of the recital one month after the end of the course (M-L). The velocity transition of the teacher's performance is also shown. In this figure, the x-axis corresponds to the sequence number of quarter notes from the first quarter note of phrase 1st A. The y-axis corresponds to normalized velocity value (not the difference in velocity shown in the previous figures).

TABLE I

Six phrases of set piece

	name	bars	marks
1	1st A	43-50	sotto voce
2	1st A'	51-56	(no sign)
3	1st B	57-62	forte
4	2nd A'	63-70	pianissimo
5	2nd B	71-74	forte
6	3rd A'	75-82	(no sign)

The velocity differences in performances 1-1 and M-L are almost the same: around 1.1, but 0.57 in performance 5-L.

While the shape of the graph of the 1-1 performance is very different from that of the teacher's performance, the shapes became very similar and the velocity difference became the smallest at the 5-L performance. Then, at the M-L performance, the velocity difference returned to 1.1. However, the shape of the graph of the M-L performance is different from that of the 1-1 performance. The shape of the graph of the M-L performance is similar to that of the 5-L performance, although the range of values became narrow.

We think these results indicate that pupil A imitated the teacher's performance of phrase 1st A in all aspects at the 5th lesson. However, after that, pupil A partially abandoned the instilled way and replaced it with her own expressiveness, i.e., she basically preserved the teacher's velocity transition but changed the range of velocity to her liking.

Figure 8 shows quarter-note-level velocity transition of four performances of phrase 2nd B by pupil A: the first performance of the first lesson (1-1), the first performance of the third lesson (3-1), the last performance of the fourth

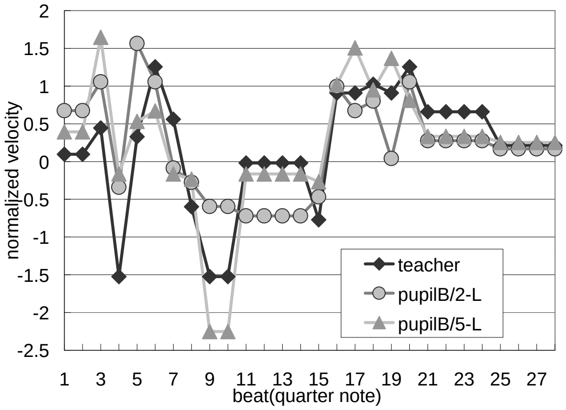

Fig. 9. Velocity of each quarter note in phrase 1st A by pupil B and teacher

lesson (4-L), and the last performance of the recital one month after the end of the course (M-L). Performances 1-1 and 4-L have almost the same phrase-level velocity difference value (0.9), and performances 3-1 and M-L also have almost the same phrase-level velocity difference value (0.5). The fifth note of phrase 2nd B is just before a large skip. The teacher performs this note at a lower volume than the fourth and sixth notes. In the meantime, although pupil A performed it more loudly than the fourth and sixth notes in performance 1-1, she came to perform it at a lower volume than the fourth and sixth notes in performances 3-1 and 4-L. However, she came to again perform it more loudly, as in performance 1-1, in performance M-L.

This suggests that her peculiar style returned even though the imitation of the teacher's way of playing was achieved once. However, her way of playing is not so bad. Therefore, a criterion to distinguish whether an interpretation is musically correct or not independent from the comparison between the teacher's performance and the pupil's performance is required. Currently, we lack such concrete criteria.

Figure 9 shows velocity transitions of two performances of phrase 1st A by pupil B: the last performance of the second lesson (2-L) and the last performance of the fifth lesson (5-L). The velocity transition of the teacher's performance is also shown. The velocity differences between these two performances (2-L and 5-L) and the teacher's performance are almost the same: about 0.5. However, the shapes of graphs 2-L and 5-L are quite different. Furthermore, the shape of the graph of performance 5-L became very similar to the teacher's graph. In particular, we can see that a conventional way to perform a "breath" (a gap between successive slurs) was instilled into pupil B by the teacher's instructions. That is, the velocity of notes just before a breath must decrease (i.e., "decrescendo") toward a breath, and then the note just after that the breath must be slightly accented. There is a breath between beat 10 and 11. Figure 9 shows that pupil B correctly performed the breath in performance 5-L, while she could not do it in performance 2-L.

Therefore, we can say that pupil B quite obediently internalized the teacher's way of performance as it is. In other words, pupil B simply imitated the teacher's way of performance.

D. Discussion: Observing progress of imitation stage

In the imitation stage, it can be assumed that the level of imitation can be simply estimated as the level of similarity between the teacher's performance and the pupil's performance. The differences decreased nearly monotonically until the third lesson for pupil A and during the entire series of lessons for pupil B as shown in Figures 5 and 6, respectively. These periods correspond to the periods when the teacher was giving them detailed instructions on how to imitate the teacher's ways of perfomance. Therefore, we can conclude that the imitation stage can probably be represented as the decrement period of the diffferences in playing style.

Moreover, the difference values at the end of the imitation stage for both pupils are about 0.6 $\sim$ 0.7. These values are close to the estimated access limit (about 0.5). Although further investigation into the value of the access limit is necessary, it may be possible to detect the end of the imitation stage when the difference value attains a certain threshold. A pupil's achievement of the access limit indicates to the teacher that he or she should move the lesson to the creation stage. However, another pupil's reaching a floor value that is larger than the access limit may show insufficient progress from the imitation stage, which indicates to the teacher that he or she should change teaching methods. In such cases, the teacher can receive suggestions on how to change teaching methods from more detailed analyses such as those shown in Figs. 7–9, e.g., have the pupil concentrate on practicing only a certain phrase.

However, reckless efforts at reaching the access limit may bring bad results. For instance, in Fig. 5, the teacher evaluated performance 3-1 as the worst even though the difference achieved a minimum value, while the teacher evaluated performance 2-L as the second-best. In this case, the teacher might have moved to the creation stage when the teacher was nearly satisfied with the pupil's performance, i.e., after finishing the second lesson.

IV. Non-Creative Process Support in a Musical Performance

When amateurs (novices, in particular) attempt to create music, they immediately face an initial but very serious barriers. For example, people usually must learn how to describe/read a score. If someone wants to perform a musical instrument, he/she must master the methods used to operate it. When someone tries to improvise in a jazz performance, he/she should have theoretical knowledge of jazz (e.g., the Berklee theory). Even for simply singing, we cannot sing a song well without any voice training. Such initial barriers are by no means negligible. It takes a very long time for a novice trumpeter just to make a sound on a trumpet. It is also really difficult to improvise based on jazz theory. Thus, these barriers prevent people from "actively" enjoying music, so they resign themselves to enjoying music only passively, i.e., just listening to music. However, many such people desire to enjoy music more actively and creatively. The world-wide "karaoke" boom suggests that there are potentially very many people who want to enjoy music actively.

Accordingly, we have been studying ways of getting rid of or at least alleviating the barriers to people directly enjoying the creation of music. Our basic approach toward this goal is using a computer to handle non-creative processes for people. We think that most of the initial barriers are merely mechanical processes. Just sounding a trumpet, just reading a score, just learning musical theory and so on are of course basic and mandatory skills and knowledge, but they themselves are not creative. The creative process is executed over such non-creative bases. Therefore, we are attempting to raise people's skill and knowledge by computer support of the non-creative processes.

However, it is important to avoid superfluous support. If everything were supported by a system, the system would eventually generate complete music by simply pushing one button; this would be the same as a CD player, and there would be no room for people to create. Therefore, we must seriously consider how and where to create the room in which people can show their creativity. Most preceding attempts and systems to support novice performers (e.g., Casio's keyboard CTK-620L that indicates keys to be operated by lighting the keys) lacked this viewpoint.

In this section, we describe a support system for jazz improvisation performance. This system deputizes the decisions on available note scales based on the theoretical analysis of chord progression. In this way, it allows people to directly create improvisational melodies without being troubled with theoretical analysis. As a result, even a novice performer can immediately begin to improvise quite well. Furthermore, this system still gives the user sufficient freedom to combine notes. Therefore, the more the performer practices, the better the improvisation becomes. Thus, this system provides people the joy of music as well as the joy of accomplishment.

A. A Function-Based Note Mapping Concept

In a typical musical instrument, a note of a certain "pitch" is constantly mapped onto a certain position of the instrument's operation interface. For example, a note whose pitch is about 440 Hz is always mapped onto the 40 th key from the right edge of a piano. Therefore, a piano player can always output a 440 Hz note only if he/she operates the 40 th key from the right. In this way, the mapping of notes in most musical instruments is based on the pitch of notes. We call this way of note mapping "pitch-based note mapping."

However, a note has other attributes, so a new way of note mapping can be designed by using an attribute other than pitch. As an alternative attribute, we employed "function of note in harmony," and we call the way of note mapping based on this attribute "function-based note mapping." The function of a note is relatively determined by the harmony. Therefore, a musical instrument based on "function-based note mapping" requires information on the background harmony (e.g., a chord name).

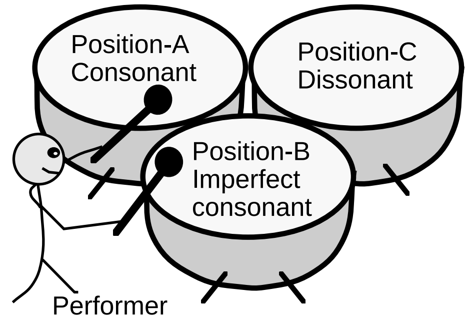

Fig. 10. Simple example of "function-based note mapping" type of musical instrument.

Figure 10 illustrates a very simple example of a "function-based note mapping" type of musical instrument. In this example, this musical instrument has only three positions, i.e., position-A for consonant note, position-B for imperfect consonant note and position-C for dissonant note. By operating one of the positions, a corresponding note that has the function of the operated position is output. When a single C-note is performed as the current background harmony, a G-note, for example, is output by performing position-A. However, if the background note changes to an A-note, the G-note changes to a dissonant note. Therefore, even if the performer continues to operate position-A, the output note changes to, for example, an E-note. Accordingly, even if operation of a certain position is continued, the pitch of the output note changes according to the background harmony while the function of the note does not change. On the other hand, although the pitch of the output note by a typical "pitch-based" musical instrument does not change, the function of the note changes according to changes in the background harmony.

B. A Musical Instrument for Jazz Improvisation

We applied this concept to construct a musical instrument for jazz improvisation. Figure 11 shows the modular structure of this instrument. The system first analyzes the chord progression of a musical piece based on the Berklee theory and then obtains available note scales for each chord. Usually, a scale consists of seven notes. Each note is named by the number of the position from the root note, i.e., I, II, III, IV, V, VI and VII, where I is the root note. This number usually corresponds to the syllable names. The position from the root note represents the function of the note. For example, the III note has the function of expressing tonality: minor or major of the chord/scale. The VII note has the function of expressing an "impression of resolution" of the chord/scale. Accordingly, we name the function of each note by the number of the note's position, e.g., the function of the IV note is named "function-IV." For example, the D-dorian scale consists of the following sequence of notes: D, E, F, G, A,

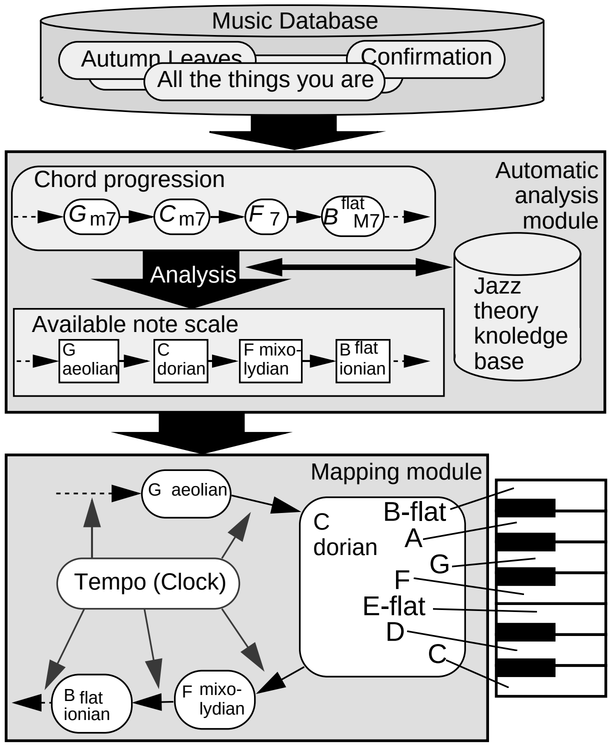

Fig. 11. Software module structure of the musical instrument for jazz improvisation based on the function-based note mapping concept.

B and C. Therefore, the function-III note of the D-dorian scale is F. The functions of the notes not included in the currently available note scale are also named based on the number of scale-notes, like function-♭II, function-♯IV, and so on. Finally, by constantly mapping a certain function to a certain position of the operating interface of the musical instrument, a "function-based note mapping" type of musical instrument can be created.

In a BeBop style jazz improvisation performance, a performer

1. reads the chord progression from a score,
2. analyzes it based on the Berklee theory,
3. obtains available note scales for each chord,
4. chooses notes from the scale, based on their functions, that are suitable for the performer's desired expressions, and
5. finally composes melodies by concatenating the chosen notes.

This is generally a very busy and difficult task. However, by using a "function-based note mapping" based musical instrument, we can directly know the function of each note at any moment in a musical piece without doing processes 1 to 3. Thus, the performer is able to immediately concentrate on the most creative process, that is, melody composition by choosing and concatenating notes based on their functions.

We conducted two experiments using a prototype musical instrument for jazz improvisation. For this prototype, we applied a MIDI keyboard (KORG M1) as the performance interface. The functions I to VII were assigned to the C to B keys, respectively. The non-scale functions were mapped onto the black keys. In this prototype, a note that is a semi-tone lower than the white key to the right of the black key is used as an expedient [4].

The first experiment was conducted to evaluate whether novice users can easily perform jazz improvisation. We employed nine subjects and let them play improvisations of "Autumn Leaves" with the prototype system. For comparison, we let them play improvisation with the same keyboard without using the "function-based note mapping" system, i.e., a conventional keyboard as it is. By inquiring about the usability of the system and asking for a self-evaluation on their performance, we confirmed that the function-based note mapping based musical instrument is siginificantly easier than the conventional keyboard, and the subjects felt that they could perform better and more "jazzy" by using it, although they do not know jazz theory and cannot play a keyboard so well.

The second experiment was conducted to evaluate whether this instrument allows enough room for improvement of performance by practice. One subject practiced "Autumn Leaves" and "All the things you are" with this instrumet for eight months. He haphazardly performed in the beginning of this term. Even if he played in such a way, the performed melody basically included only theoretically correct notes only if he performed only the white keys. However, the performance was rather poor. Progressing through practice, he began to attempt various combinations of the functions not only of the white keys but also of the black keys, and began to understand the "feeling" of each function. Finally, he became able to improvise by using the feeling of the function, and the performance was remarkably improved and became really jazzy. Thus, this instrument is not only easy and familiar for novices but also gives them enough room for building and expressing proficiency. This feature grants people the joy of creating musical performance.

V. How Can a Computer Facilitate Musical Creation?

In the previous three sections, we overviewed our three attempts to facilitate creative activities in music. We would like to emphasize that all of our attempts are "human centered." Our final goal is to enhance human musical creativity and to enrich the active joy of music. That is, what becomes creative should be humans, not computers.

Since the dawn of the computer, many trials of computer music have been attempted. Currently, computer music research has spread in various directions: sound generation, sound recognition, music recognition/understanding,

[4]Because of this mapping method for the black keys, an in-scale note is assignd to a black key in some cases. For example, in Fig. 11, the E♭ note is mapped onto the E key. Therefore, the D note is mapped onto the E♭ black key. The D note is in-scale and the function-II note, and the same note is also mapped onto the D key, too. This problem arises because we applied this novel note mapping system to a traditional keyboard. To sufficiently benefit by this concept, we need to design a new specialized interface. This remains as a future work.

automatic performance/accompaniment, algorithmic composition, and so on [6]. Recent computer music research has generally been conducted in the artificial intelligence research domain. Therefore, most efforts aim at machine intelligence and machine creativity, which is a dream of artificial intelligence research. As a final result, a computer musician that performs and composes fantastic music is expected to appear.

However, do we really desire such a computer musician, despite the shortage of good composers and musicians? We doubt that there are actual demands for computer musicians except for some special situations. We hope that artistic creativity, including musical creativity, remains dependent on humans, not machines, forever. Consequently, we believe that enhancing human musical creativity, not substituting computers for humans, is the best way to enrich the musical culture in the future.

In the research on creativity support technology, the appropriate division of the entire creative work between humans and computers is a keypoint. Namely, a computer should be in charge of what computers are good at, while a human should be in charge of what humans are good at. We think this concept is applicable to the musical creativity support domain. Therefore, we developed the systems described in the previous sections along this concept.

The first thing that a computer is good at is observing things from an objective viewpoint. For example, by applying a statistical analysis method, the computer can objectively reveal actual conditions. Such an objective representation provides typically biased people rich and stimulating information. Music-AIDE shows the structure of a musical piece from an objective viewpoint by a dual-scaling method. Furthermore, Music-AIDE can provide suggestions for new directions of melody creation. Here, we think the way of giving the suggestions is important. For example, several automatic composition systems, e.g., Koan Pro[7], production software, and a system in the literature [8] are attempting to stimulate composition by automatically providing generated pieces of melody. While this is one way of suggesting new directions of melody, it requires the quality of a melody to exceed a certain criterion because a poor melody would not be so helpful. However, the quality of melodies generated by such an automatic composition system is currently not sufficient. Therefore, we think provision of indirect information is practical and useful.

In the knowledge conveyance analysis for piano lessons described in Section III, we also utilize an objective viewpoint. The characteristics of this attempt are the following two points: the provided information is meaningful not only for students but also for teachers, and not only the situation of the progress of lessons but also the personalities of the students are also obtained. Many types of piano lesson (support) software have already been developed [9]. Most of them help students study piano playing. In other words, these software products are deputized for the work of teachers. There is no system that supports teachers as well as students as far as we know. Our system behaves as if it were a third person who objectively observes the lessons and gives suggestions to both the teachers and the pupils.

The second thing that a computer is good at is very fast computation and processing of a massive amount of formal data. We utilize this feature in our musical instrument for jazz improvisation. Musical theory, including jazz theory, involves well-formalized data, and theoretical analysis can basically be done in a mechanical manner without creativity. However, the analysis and applying the analysis results to performance must be executed very quickly. Therefore, we believe this task is suitable for computers. By leaving this mechanical task to computers, people can concentrate on the creative process. As a result, people may be able to achieve a better preformance than that of people doing the entire process.

Consequently, we think that the way of deputizing computers for human effort is the wrong way. We agree that it is a technically interesting challenge to create a virtual performer or a virtual composer, and we are watching the development of this research area with great interest. Machine-learning of musical knowledge (e.g., [10],[11]), huma-like computer performers (e.g., [12], [13]) and computer composers (e.g., [8]) are very exciting technical challenge. However, to really enrich the musical culture and to practically contribute human musical activities, we think that an invasion of the sanctuary of creativity should be avoided: computers should be devoted to mechanical tasks.

VI. Conclusions

This paper discussed how computers can and should facilitate creative activities in music. We described our three attempts to enhance human musical creativity: Music-AIDE to support musical divergent thinking, musical knowledge conveyance support in piano lessons, and a musical instrument for jazz improvisation performance that supports non-creative processes. Based on our experiences in these attempts, we discussed how and where computers can contribute to the musical creation process. We pointed out that computers should be devoted to only mechanical processes and should not invade the human sanctuary of creative processes.

We wonder that computer music research currently focuses too much on the achievement of machine creativity. Unfortunately, there are few research efforts that aim to enhance human musical creativity. We hope that this situation will change and that more research will be directed toward facilitating human musical creativity.

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