Thermoscore:
A New-type Musical Score with Temperature Sensation

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ABSTRACT
In this paper, we propose Thermoscore, a musical score form that dynamically alters the temperature of the instrument/player interface. We developed the first version of the Thermoscore display by lining Peltier devices on piano keys. The system is controlled by MIDI notes-on messages from an MIDI sequencer, so that a composer can design songs that are sequences of temperature for each piano key. We also discuss methodologies for composing with this system, and suggest two approaches. The first is to make desirable keys (or other keys) hot. The second one uses chroma-profile, that is, a radar chart representation of the frequency of pitch notations in the piece. By making keys of the same chroma hot in reverse proportion to the value of the chroma-profile, it is possible to constrain the performer's improvisation and to bring the tonality space close to a certain piece.

Keywords
musical score, improvisation, peltier device, chroma profile

1. INTRODUCTION
In a very real sense, the written score does not present the full picture of a musical piece. What is written in the score is only the minimum information needed to re-create the music. For instance, the time resolution of note-on timing is at most in 64th notes, and moreover, note-off timing is completely at the discretion of the performer. Instructions for tempo are described with just a few simple words; those for key touch are expressed even more simply, and not for individual notes. In the process of playing music, a musical performer interprets them and compensates for the lacking information. Therefore, music performance differs from performer to performer. Also, if the performer plays something slightly different from what is written, it can be considered permissible as an ad lib arrangement that comes from his/her individual character. In this sense, we can define the score as a set of minimum instructions from a composer to a performer.

If we refer to graphic scores and text scores, several pieces are open to a great variety of interpretations. For example, the graphic score of "Concert for Piano and Orchestra" by John Cage (Figure 1) allows many more interpretations than traditional musical scores, especially in the sequence of the notes. The text score of "RIGHT DURATIONS" by Karlheinz Stockhausen (Figure 2) never specifies the pitches of any notes, but provides more descriptions of duration instead. In such cases, we can say that such scores set fewer constraints on a performer's improvisation.

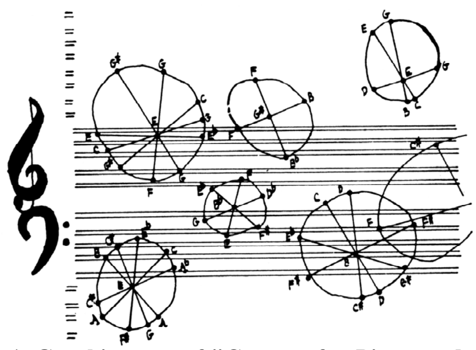


Figure 1. Graphic score of "Concert for Piano and Orchestra" (John Cage)

RIGHT DURATIONS

play a sound
play it for so long
until you feel
that you should stop

again play a sound
play it for so long
until you feel
that you should stop

and so on

stop
when you feel
that you should stop

but whether you play or stop
keep listening to the others

At the best play
when people are listening

do not rehearse

Figure 2. Text score of "RIGHT DURATIONS" (Karlheinz Stockhausen)

However, without regard to graphic or text, such scores are still visual images laid down on flat paper. Today we can make many choices from among a variety of media. We do not need to cling to static media, or even stick to visual media. With Thermoscore, we may succeed in conveying information that is impossible to express with static visual media.

2. EXPANSION OF SCORE

2.1 Dynamic Scores

Generally, it is hard to describe time on a planar surface, for spatial representation does not necessarily correspond to individual time sensation. Accordingly, accelerations or decelerations in velocity cannot be described precisely by musical characters, and the rhythms or grooves that the composer intended cannot be expressed faithfully by musical notes. To convey these types of information, it would be more effective to animate the score. The movements of notes in the score would more intuitively display accelerations, rhythms, and grooves.

In 2003, the first author of this paper crystallized this concept in "Graphic Score Animation for Two Pianos." In this work, the graphic score animation, divided right and left, was projected onto a screen. Each part presented a non-traditional score for one of the two pianists (Figure 3). The system also functioned as a conductor that synchronized the two performances by visual motion. This score described time information with clockwork precision. In this case, the composer did not write a static score, but instead created an animated score with Macromedia Flash.

Figure 3. Performance of "Graphic Score Animation for Two Pianos" [4] (Homei Miyashita)

At first glance, this system seems to be similar to some media art that converts music to images through the medium of the computer (like "MUSIC PLAYS IMAGES X IMAGES PLAY MUSIC" by Iwai et al.[5]). However, this "Graphic Score Animation" is completely different; it converts images to music through the medium of the performers.

There is another type of dynamic score that is not sequenced but interactive. For example, the performance of Yolande Harris et al.[1] used a moving graphic score created from signals from the audience's chairs. Introducing interactivity into a dynamic score is easy, and it must lead to new musical expressions.

2.2 Scores for Non-Visual Sensation

Musical performers frequently plays music on stage from memory. The main reason for memorizing the score is because s/he can then concentrate on the actual performance. Processing a flood of visual information might have a negative effect on centered music performance. Therefore, it would be ideal if the player has only to concentrate on interaction with musical instrument.

Accordingly, there have been some attempts to convey musical information via non-visual (and non-auditory) senses. A bio-feedback system developed by Nagashima [6] uses electric pulses as the feedback signal. Using this system, Akamatsu et. al. created a live performance, "Flesh Protocol," in which those signals are sent to a dancer. This system can be related to a musical score that uses non-visual senses. (Moreover, this can be regarded as a dynamic score.)

On the other hand, vibrotactile suits developed by Gunther et al. can transfer musical information by vibrations on the surface of the body [2], though they were made to enable audiences to listen to music using the sense of touch. This system is controlled via general audio sequencing software, so it also can be called a dynamic score.

Both systems were designed as wearable devices. Therefore when they are used as a score, to some degree they will become hindrances to the performer's movement. When designing a new system, we must create an environment in which the performer can concentrate on playing. Consequently, to display the composer's requirements or constraints more effectively without disturbing the actual playing, we chose temperature as a sensation to convey information. With a few exceptions like the Theremin, the performer touches the instrument during a musical performance. Music arises from interface between performer and instrument. As a result, the more s/he concentrates on playing, the more of the senses in the fingertips become acute. We focused attention on that contact point, and considered developing some sort of 'score display' there. Musical instrument must be an input device for a music performer, but it could be an output device at the same time. By changing temperature at the interface with the instrument, we may be able to communicate which note the composer wants (or does not want) to be played, or how fast or how loud it should be played.

3 SYSTEM DESIGN

3.1 Thermoscore Display

To control the temperature of the interface between performer and instrument, we adopted Peltier devices for the Thermoscore display. A Peltier device is a thermoelectric cooler that works as a heat pump. It is a sandwich formed by two ceramic plates; when an electrical current is applied, it transfers heat from one side of the device to the other (Peltier effect). By reversing the current, we can interchange functions, cooling and heating. As we started designing the first version of the Thermoscore display, we chose the piano keyboard because the piano is one of the most common and versatile instruments. Also, the size and shape of Peltier devices fit in well on piano keys. (Figure 4)

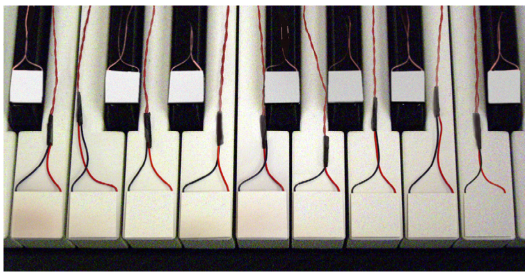


Figure 4. Peltier devices on *Thermoscore* display (piano version)

3.2 MIDI Control

As shown in Figure 5, the Thermoscore system is controlled by Musical Instrument Digital Interface (MIDI) signals. The MIDI-to-Temperature converter receives a MIDI note-on messages from the MIDI sequencer, and sends electricity to the Peltier devices of the corresponding keys on the Thermoscore display.

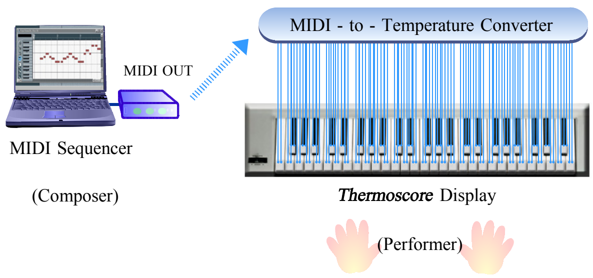


Figure 5. The MIDI Control System of Thermoscore

With MIDI, we can compose songs for this system by trial and error, using general MIDI sequence software. It is easy to apply existing MIDI files in a piece or to synchronize the thermoscore with another MIDI system, and moreover, it is possible to build a progressive system using MIDI input from the instrument used for the Thermoscore display. Note that in principle, this system is not a feedback system from an instrument. Signals flow only in one direction, i.e., from composer (or his/her song) to performer, and the instrument serves simply as an output device. In other words, the instrument sends messages to the performer by means of temperature, receives his/her action as 'feedback', and then transforms the action into sound.

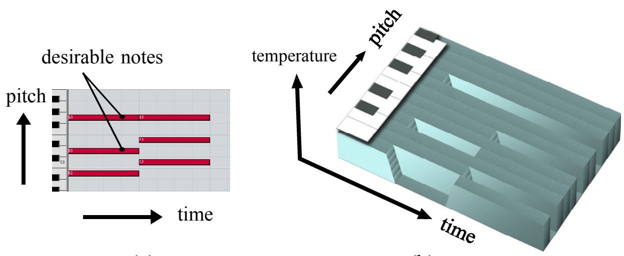
4. SONG DESIGN (COMPOSITION)

4.1 Displaying Keys

In this section, we discuss methodologies for composing songs for the Thermoscore system. As previously described, a score is a set of minimum requirements from a composer to a performer, or, a set of constraints on the performer's improvisation. The first method we suggest is to display key and harmony constraints in terms of pitch.

Nobody can touch a very hot object for a long time. When objects are much hotter than body temperature, a person may pull his/her hand away immediately by reflex action. In this manner, if we control Thermoscore to make some keys so hot that the performer cannot hold it as tenuto, the sound tends to be short, or, a passing note toward some note that is not as hot. Of course, we don't need to make the keys so hot that they burn the performer's fingers. What is important is to send the message. In this way, all we have to do is to make every key hot, except the notes indicated by the composer. First, the composer describes chord progressions and available notes on the piano-roll window in a MIDI sequencer. To apply them to Thermoscore, the piano-roll image is 'reversed,' like a negative film. (Figure 6)

Needless to say, it is possible to instruct the performer to 'Strike the key while it is hot,' and in that case we don't need to 'reverse' the piano-roll image.



(a) (b)

Figure 6. Example of (a) music image in composer's mind and (b) corresponding thermoscore image

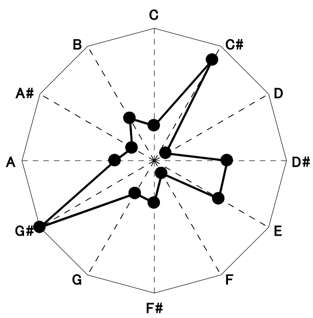
In this system, chords proceed with time, but by utilizing a MIDI triggering system, like the touchtracks function in Logic Audio Software, it becomes possible to trigger the progression in real-time, This also allows a composer to control the performer's playing from a seat in the audience!

The latency time from the beginning of heating to the performer's recognition depends on the performer, but it takes a few seconds. When composing songs for this system, the composer must account for that latency. Also, the performer does not need to hesitate to hit the keys. S/he can play freely, and the hot keys will be reflected in the duration of the notes.

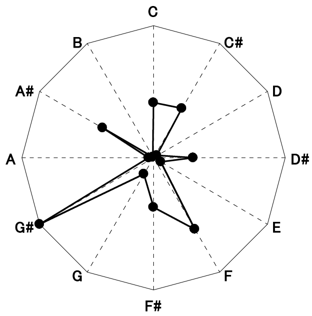
4.2 Stochastic Control from Chroma-Profile

Constraining improvisation is a kind of stochastic control. Therefore, we developed chroma-profile, which is a radar chart representation of the frequency of pitch notation in the piece, computed from MIDI data [2]. With this representation, we could visualize not only the music's tonality (or modality) space but also the characteristics of the composer and the era when it was composed.

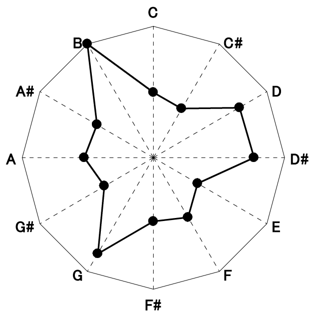
For example, Fig 7(a) is a chroma-profile from the 3rd movement of Beethoven's "Moonlight Sonata," Op.27 No.2. This piece was written in C sharp minor, so frequencies in the tonic (C#) and dominant (G#) are higher than in the others. Figure 7(b) is a chroma-profile from Chopin's "Minute Waltz," Op.64-1; it was written in C# major, so frequencies in the tonic and dominant are high, but not as high as in the previous composition. Finally, Figure 7(c) is a chroma-profile from Schoenberg's "Six little pieces for piano," Op. 19, which was composed with a backdrop of atonalism. Every note tends to be used at more equable frequency.



(a) "Moonligh Sonata" Op.27 No.2 (L.v. Beethoven)



(b) "Minute Waltz" Op.64-1 (F. Chopin)



(c) "Six little pieces for piano" Op. 19 (A. Schoenberg)

Figure 7. Examples of Chroma-Profiles (Normalized to the maximum frequency)

To constrain improvisation and to bring the performance close to a certain piece, an approach using chroma-profile will work. Let us suppose that a performer is not inclined to hit hot keys. Under this supposition, we have only to make keys with the same letter names (same chromas) hot in reverse proportion to the value of the chroma-profile. For example, the thermoscore to achieve the performance of the "Moonlight Sonata," is shown in Figure 8. The form is duplicated-shaped, for a chroma is a cycle of notes within the octave. Temperatures of the tonic(C#) and dominant(G#) keys are set to be cooler here.

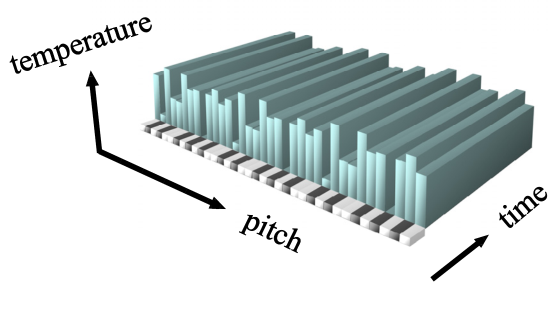


Figure. 8 Thermoscore that is expected to lead to the performance of the "Moonlight Sonata" Op.27 No.2

5. CONCLUDING REMARKS

Needless to say, results will vary depending on the performer. Note that, however, that our original purpose was not to get the music precisely as expected. If a composer wants to control the music exactly, s/he should control the instrument directly via MIDI. As mentioned previously, a musical performer interprets, adds, and sometimes ignores information from the composer, but that process makes music even more vital, and that is exactly the talent of the performer. This is why many composers use the traditional medium called a 'score' even today. A score is not an order from a composer to a performer, but a sort of communication medium that enables them to create music together.

We believe that the best advantage of Thermoscore is that it conveys the feels existence, emotion, and 'body warmth' of the composer to the performer. All music is product of a collaboration between composers and performers. Usually they do not (or can not) meet each other, but at any rate, performers should get a sense of communion with the composers, whatever kind of score is used.

6. FUTURE WORKS

Next we plan to conduct a few evaluation experiments of the Thermoscore system, and design a visualisation system so that the audience can perceive the effect.

7. ACKNOWLEDGEMENT

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