GESTURECHORDS: TRANSPARENCY IN GESTURALLY CONTROLLED DIGITAL MUSICAL INSTRUMENTS THROUGH ICONICITY AND CONCEPTUAL METAPHOR

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ABSTRACT

This paper presents GestureChords, a mapping strategy for chord selection in freehand gestural instruments. The strategy maps chord variations to a series of hand postures using the concepts of iconicity and conceptual metaphor, influenced by their use in American Sign Language (ASL), to encode meaning in gestural signs. The mapping uses the conceptual metaphors MUSICAL NOTES ARE POINTS IN SPACE and INTERVALS BETWEEN NOTES ARE SPACES BETWEEN POINTS, which are mapped respectively to the number of extended fingers in a performer's hand and the abduction or adduction between them. The strategy is incorporated into a digital musical instrument and tested in a preliminary study for transparency by both performers and spectators, which gave promising results for the technique.

1. INTRODUCTION

When designing Digital Musical Instruments (DMIs), the mapping strategy used to connect a performer's actions to an auditory response is of critical importance, and can "define the very essence of an instrument" [1]. As such, a great amount of research has gone into designing mapping strategies that provide and enable an expressive [2, 3] and virtuosic performance [4].

This paper seeks to explore the use of conceptual metaphors in freehand DMI mapping by their iconic representation, drawing influence from gestural sign languages such as American Sign Language (ASL). An iconic representation is the use of resemblance or similarity to encode meaning [5], and many gestures in ASL use it to encode conceptual metaphors [6]. Some signs that use this method of encoding their meaning can often be comprehended by those with no experience in signed languages [7] due to their physical resemblance to the concept they represent. This paper seeks to begin investigating the prospects of using similar techniques to encode musical meaning in freehand gestural control, specifically focussing on whether using this technique in DMI mapping design provides a high level of "transparency" as defined by Fels *et al.*, which "provides an indication of the psychophysiological distance, in the minds of the player and the audience, between the input and output of a device mapping" [8]. More succinctly: Does using iconic representation of conceptual metaphor in mapping strategies make for effective, transparent control in freehand gestural musical instruments?

To explore this, a DMI mapping strategy, GestureChords, has been created. This strategy encodes conceptual metaphors relating to musical concepts in a series of hand postures, via iconic representation, to be used in DMIs for selecting chord variations. This strategy is then incorporated into a DMI, and tested for its transparency.

2. BACKGROUND

Due to the uncoupling of a musician's actions and the resulting audio response, DMIs need a specified mapping strategy in order to re-establish the connection, which can come to define a musical instrument [1]. Thus, developing a successful mapping strategy is of the utmost importance in DMI design.

2.1 Mapping

The strategies used to map input data to musical parameters in DMIs commonly fall within one-to-one, divergent (one-to-many), convergent (many-to-one) and many-to-many classifications [9, 10]. However, the most successful and expressive mapping strategies have been found to be those that employ multi-parametric control with a high degree of complexity [11].

This desire for complexity, as well as advances in gestural recognition technologies [12–14] has lead to the emergence of more abstract applications of mapping, as highly complex strategies can be devised independently and then taught to computers using machine learning techniques [15]. While this has lead to the ability to make complex mappings with relative ease, there still remain many challenges to be overcome. Notably, "how are meaningful and effective mappings created, that seem to evoke the *correct* musical response?"

One solution to this issue is to allow a musician to decide on their own mappings [16, 17]. While this provides a meaningful mapping for the individual performer who designed them, this does not necessarily mean that another musician would find these mappings intuitive, nor an audience member in any performances given, whose perception of a performance plays an important role in instrument design [18]. This technique also requires a lengthy setup process on the part of the performer, and mappings may also need to be set in a prescribed order, requiring premature commitment from the performer [19] as they may be difficult to alter later.

2.2 Conceptual Metaphor

The use of the term metaphor in Human-Computer Interaction (HCI) has a large scope of potential meanings and uses, and requires contextualisation [20]. Here, the term refers to conceptual metaphor, or when one concept is explained in the terms of another [21]. It is a useful concept in HCI for explaining the behaviour of computer software, and allows users to grasp abstract concepts quickly via an association with a more familiar domain [22]. Using it provides a way to "piggyback" understanding of abstract concepts on the structure of concrete concepts [23]. A classic example of this is the DELETING IS RECYCLING conceptual metaphor, in which files users wish to delete are temporarily stored in a specific directory named "Recycle Bin" (on Windows operating systems), which then "recycles" the material it is made from (in the computer's case, memory instead of paper).

This application of metaphor has also been explored in DMI design [4, 8, 24]. Fels *et al.* [8] and Wessel and Wright [4] examine the effectiveness of using conceptual metaphors in instrument mapping design to allow for expressive and virtusoic performance. Wessel and Wright use conceptual metaphors described by Lakoff and Johnson [21] to influence the design of several instruments, while Fels *et al.* describe how this can be used to increase the "transparency" of the instrument's mapping. Here, transparency describes how comprehensible the mapping is to a player and observer (ranging from "opaque" to "transparent"), a quality that contributes to an instrument's expressive and virtuosic potential. A similar concept is explored by Reeves *et al.* in more general HCI contexts, particularly focussing on a spectator's ability to perceive a user's "manipulations" and the resulting "effects", on a scale from "hidden" to "amplified" [25]. It is important to consider the spectator's understanding of an instrument's mapping as well as the performer's in DMI design, as the ability for an audience to perceive how an instrument is controlled is a critical aspect of musical performance [18, 26].

HCI and DMI design are not the only domains to make use of conceptual metaphor. In fact, conceptual metaphor is a tool so ubiquitous that it is used reflexively (without conscious thought) [21], and is common in natural language. For example, the conceptual metaphor ARGUMENT IS WAR described by Lakoff and Johnson: "Your claims are *indefensible*", "He *attacked every weak point* in my argument" and so on.

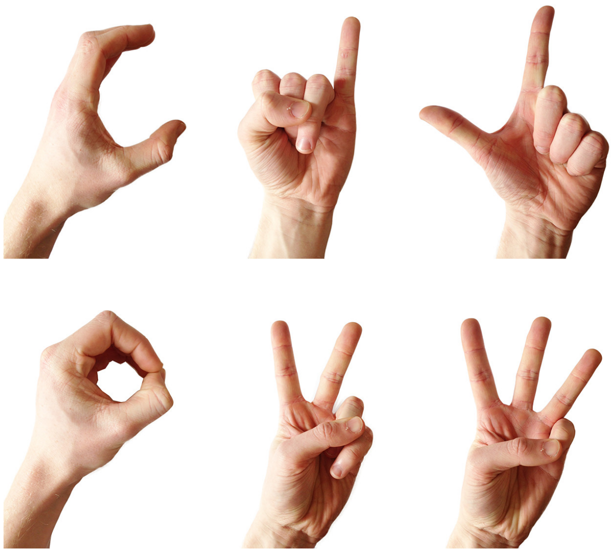

Figure 1: ASL fingerspelling letters: 'C', 'I', 'L', 'O', 'V' and 'W'.

In the design of DMIs that use freehand gestures as their interaction method, the most useful derivation of linguistic conceptual metaphor is through its prevalence in freehand gestural languages, or sign languages.

2.3 Iconicity and Conceptual Metaphor in Sign Language

Iconicity is found in signs that represent their objects mainly by their similarity, or perceived resemblance, no matter what their mode of being [5]. The use of iconicity to encode meaning is common in gestural sign languages. In this case, signs visually resemble that which they represent, enabling them, in some cases, to be recognised by non-signers [7].

Examples of this can be found in the ASL fingerspelling alphabet. This alphabet is a system of 24 static hand postures and two dynamic gestures used to encode the standard English alphabet, all performed on one hand. These postures can be said to be *emblematic*, which refers to nonverbal acts which have a direct verbal translation, for which a precise meaning is known by most or all members of a group or culture [27]. Emblematic postures and gestures are often iconically encoded, and many of the ASL letters are iconic representations of their written counterparts; the hand shapes used to encode them physically resemble the shapes of the letters, such as 'C', 'I', 'L', 'O', 'V' and 'W' (Figure 1). The postures can be signed on either hand, and are expressed on the left hand as a mirror image of the right.

Conceptual metaphors are also regularly expressed through iconic representation in sign languages. An example, described by Taub [6], is the conceptual metaphors of INFORMATION ARE OBJECTS and HEAD IS A CONTAINER, which are iconically expressed in the ASL sign LEARN (Figure 2), in which the signer gestures the picking up of information and the placing of it in

Figure 2: The ASL sign LEARN

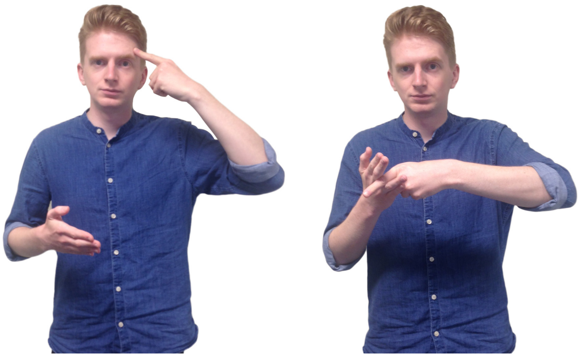

Figure 3: The ASL sign THINK-PENETRATE

one's head. Another is the ASL sign THINK–PENETRATE (Figure 3). This sign begins with the dominant hand pointing with the index finger at the temple, which then moves through or *penetrates* the fingers of the non-dominant hand. This sign can be interpreted as "they finally got the point" and makes use of the same metaphors as the sign LEARN, elaborating on the HEAD IS A CONTAINER metaphor with CONTAINERS HAVE BOUNDARIES, while INFORMATION ARE OBJECTS leads to INFORMING IS SENDING. The sign iconically depicts the information object (the thought) being sent from one container (the signer's head) to the boundary of another container (the signer's hand, representing another's head), penetrating it and entering (the thought enters the head).

3. GESTURECHORDS

The mapping in GestureChords is based on an iconic representation of conceptual metaphors. Particularly, the metaphors of MUSICAL NOTES ARE POINTS IN SPACE and INTERVALS BETWEEN NOTES ARE SPACES BETWEEN POINTS. These metaphors have been inferred as follows: Music is experienced through time; time is expressed through spatial metaphors (TIME IS A MOVING OBJECT [21]); thus, notes are points in this musical space that are reached as we travel through it (or it travels past us). As notes are experienced, they are identified via differences in pitch; difference in pitch is often expressed in spatial terms (such as UP–DOWN [24]); thus, differences in pitch between notes (or intervals) are distances between points.

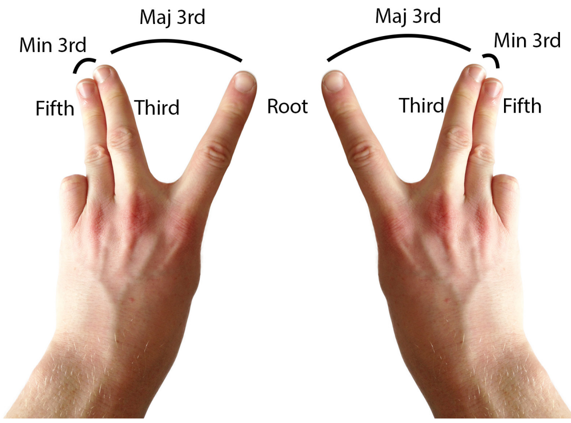

Figure 4: A major triad chord represented using the GestureChords strategy, as expressed on both the left and right hands.

These metaphors can also be said to be expressed in Western musical notation: one travels through the music from left to right; notes are represented by black points on the stave, whose position on the up–down axis on ledger lines denotes pitch; while the intervals between notes are represented by the distance (on the vertical axis) between these points.

The GestureChords system of hand postures uses the conceptual metaphors above to encode chord shapes that are intended for use in free hand DMIs. The mapping strategy considers the number of extended fingers on the hand and the spacing (abduction) between them. The MUSICAL NOTES ARE POINTS IN SPACE metaphor is iconically mapped to the tips (or points) of extended fingers, while INTERVALS BETWEEN NOTES ARE SPACES BETWEEN POINTS is iconically represented by the spaces between the fingers. As such, each extended finger represents one note in the resulting chord, while the adduction or abduction between consecutive fingers represents one of two intervals between these notes. Adducted (close together) fingers represent minor thirds (the small gap representing the smaller interval encoded) while abducted (spread out) fingers represent major thirds (the large gap representing the larger interval). As in ASL fingerspelling, the mapping is designed to be used with both hands, with signs expressed on one hand as a mirror image of their expression on the other. Accordingly, the index finger always represents the root note, while subsequent fingers represent notes above it. The thumb is excluded from the mapping.

For example, a major triad chord is represented by the hand posture in Figure 4. The three extended fingers represent the three notes used (e.g. C–E–G in C Major). The abducted index and middle fingers encode the major third between the root and the third of the chord (C–E), while the adducted middle and ring fingers encode the minor third between the third and the fifth of the chord (E–G).

The encoding above constrains GestureChords to representing a maximum of four note chords, and encodes 14 different chord types.

The full range of hand postures is shown in Figure 5. The choice of these postures are the natural result of following the strategy set out above. It should be noted that the final possible hand posture of four abducted fingers has been omitted, as in this mapping it represents an augmented chord, which is already represented, in an alternative voicing. The mapping encodes root, minor third, major third, diminished, minor, major, augmented, diminished seventh, diminished major seventh, minor seventh, minor major seventh, dominant seventh, major seventh and augmented major seventh chords.

4. PILOT STUDY

To evaluate the efficacy of the GestureChords mapping strategy a DMI was built that incorporates a Leap Motion optical sensor [28] and a simple one octave virtual keyboard embedded in the instrument's software user interface (Figure 6). A user interacts with the instrument by positioning one hand above the Leap Motion sensor to use the chord postures, while using a mouse with their other hand to interact with the virtual keyboard (Figure 7). The software analyses the Leap Motion's input using an Adaptive Naïve Bayes Classification algorithm from The Gesture Recognition Toolkit [29] to determine which chord has been selected. The virtual keyboard then selects the root note and triggers the chord. The application provides visual feedback, informing the user as to which chord and root note is currently selected, as well as the connection status of the Leap Motion.

Note selection is a difficult challenge for freehand gestural instruments. Previous studies [30, 31] have shown that this is often due to a lack of tactile and visual feedback, usually given by a physical interaction surface found on traditional instruments. The decision to select root notes and trigger the chords on a virtual keyboard has been made in order to avoid these issues and focus the attention of the study on the GestureChords postures.

4.1 Methodology

In this pilot study, responses from participants in a qualitative study are compared against the transparency scale described by Fels *et al.* (Figure 8) [8] to give an indication of the transparency of the GestureChords mapping. The scale consists of two axes ranging from opaque to transparent, one for the performer's perception and the other for their audience. Successful mappings are those that score highly on both axes, transparent for both the performer and their audience. The study is split into two tests, one for each axes and each with its own set of participants. In both tests, the musical expertise of the participant is established by asking for an explanation of the theory behind major, minor, augmented, diminished, minor seventh and major seventh chords.

The technique used in the performer test draws from the discourse analysis technique described by Stowell

Figure 5: The full range of hand postures used to select chords in GestureChords.

et al. [32], which consists of: *free exploration*, where a user is allowed to explore the instrument freely; *guided exploration*, where a user is asked to influence their exploration from an example performance; and a *semi-structured interview*, where the user's subjective experience is evaluated. The method implemented in this pilot study consisted of free exploration, guided exploration and a questionnaire. The questionnaire is used to focus the participants responses to the mapping strategy, and gauge its transparency with regards to the performer's perceptions.

The methodology for the audience test is adapted from the spectator evaluation technique described by Barbosa *et al.* [33]. In this technique, a video of a performance is presented to participants along with a questionnaire for analysing the participant's comprehension of *cause, effect, mapping, intention* and *error*. In this test, participants are

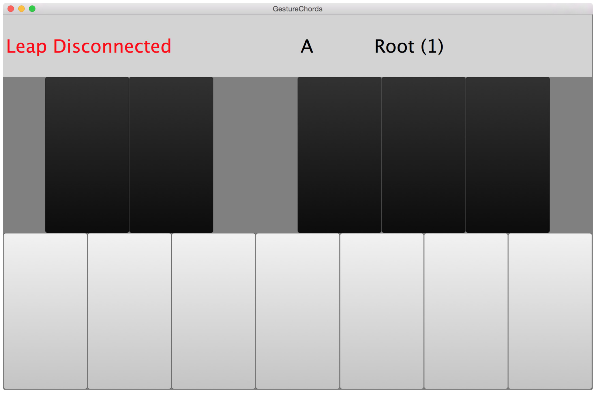

Figure 6: The GestureChords application.

Figure 7: A GestureChords performance.

shown a video of a performance with the GestureChords application and asked a series of questions, which in this study focus on the comprehension of *cause, effect* and *mapping*, in order to determine an audience's perception of the mapping's transparency.

The video allowed the participants to clearly see the GestureChords hand postures being performed as well as the performer's interactions with the software interface.

In both tests, a full description of the mapping strategy was initially withheld, and then revealed to the participant midway through the test. This was done to compare the participant's perception of the mapping with and without knowledge of the strategy employed, and to test if they were able to independently perceive the iconic representation of the conceptual metaphors without prompting.

4.2 Results

Six participants took part in the performer test, while four took part in the audience test. In both tests the participants ranged from musicians with advanced knowledge of chord theory to relative novices, whose descriptions of major and minor chords did not extend further than informal observations, such as "major is happy" and "minor is sad".

4.2.1 Performer

All of the performance participants agreed that the method for controlling the instrument was clear, and all recognised

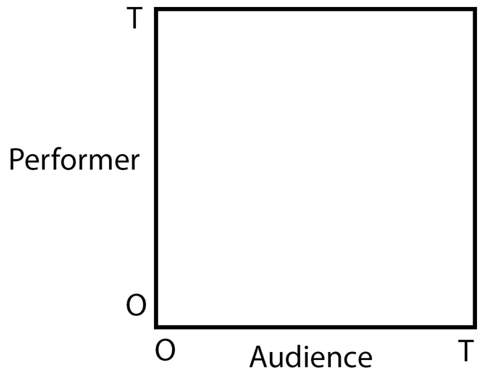

Figure 8: The Mapping Transparency Scale [8].

that different hand postures triggered different chords, while the virtual keyboard selected the root note and triggered the chord.

Three users, two of which displayed advanced knowledge of musical theory while the other had limited knowledge, managed to recognise and describe the mapping strategy before it was revealed to them, noting that abduction and adduction variation mapped to major and minor thirds, while each finger added a note to the chord. Two participants simply noted that different postures triggered different chords, while one participant offered no description.

Participants noted that the instrument was "intuitive" and "entertaining to play", and two users remarked that they believed the instrument would be "suitable for beginners in music theory".

Once the mapping strategy was revealed, all the participants strongly agreed that they understood the concept, while five of the six agreed that the iconic representation aided in their understanding of the mapping. All the participants agreed that the mapping was an effective method of representing chords.

4.2.2 Audience

Corresponding to *cause* and *effect* comprehension, all of the audience test participants agreed that the method of controlling the instrument was clear. Two respondents were able to give detailed responses on how they perceived the instrument to be controlled and how the resulting auditory response was achieved, while two users was unable to fully perceive the controls, and gave vague responses.

Regarding *mapping* comprehension, three of the four participants agreed that the controls clearly related to the auditory response. All the participants correctly recognised the mapping of the number of notes in the chord to the number of extended fingers, while two participants managed to recognise the relation between abduction/adduction and major and minor third intervals.

Once the mapping strategy had been revealed, all the participants agreed that the relationship between a chord and its hand posture was easily perceived, and that the strategy was effective at encoding chords.

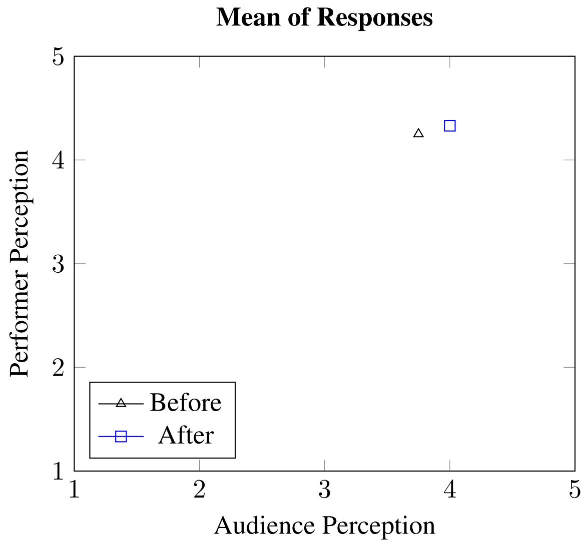

Figure 9: Mapping Transparency of GestureChords

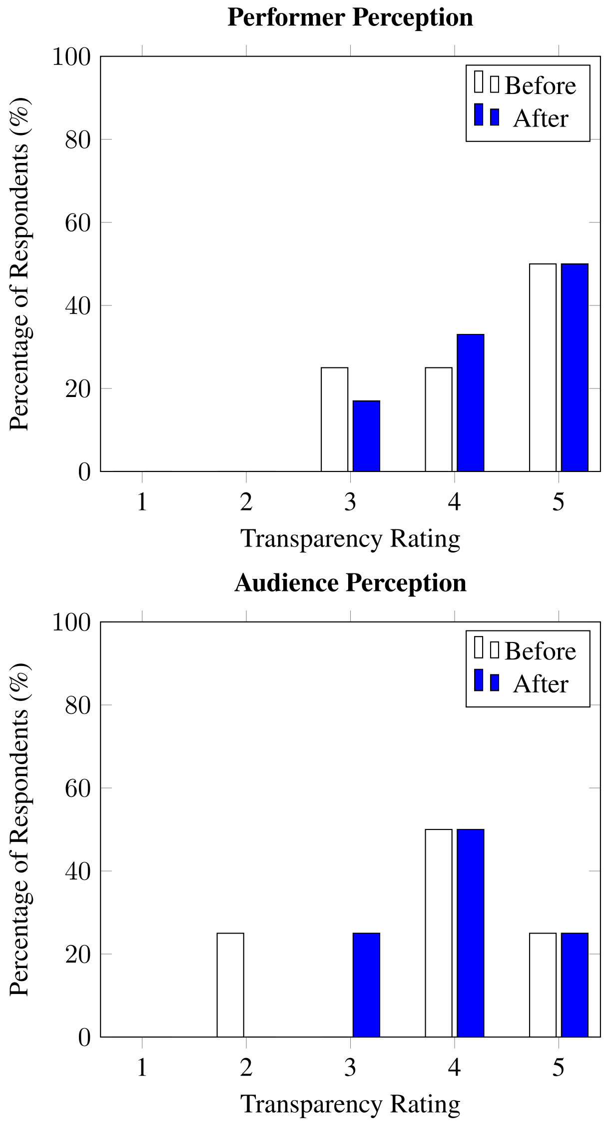

Figure 10: Transparency Ratings of GestureChords

4.3 Discussion

The results of this initial pilot study show positive results for GestureChords and the use of iconic representation of conceptual metaphor in DMI mapping design.

It should be noted that due to the small size of this study these results cannot be considered conclusive, a more detailed and thorough investigation into the technique is required in order to determine its true effectiveness. However, the positive results from this study are promising, and suggest that using iconic representation of conceptual metaphor in gestural musical instrument mapping design can promote a transparent mapping strategy for both performers and their audiences, and that further exploration into this technique is worthwhile.

An interesting observation that arose was that the system may be appropriate for music theory novices. This highlights an area of possible future research, and may relate to users being able to use GestureChords to cognitively offload [34] the concepts of chord selection to their hands, allowing the postures to become epistemic actions [35].

Both performers and audiences were asked to rate their opinion from 1 (opaque) to 5 (transparent) on how obvious they perceived the mapping to be. The mean averages of these responses have been mapped onto the Mapping Transparency Scale of Fels *et al.* [8] for both before and after the mapping was revealed to participants, shown in Figure 9. Figure 10 shows the spread of responses in percentages. This preliminarily rating can provide a rough guide, and suggests that the GestureChords mapping strategy has been successful in providing a transparent mapping strategy for freehand gestural control of chords, and that the mapping was perceived to be transparent prior to participants gaining knowledge of the mapping strategy as well as after. This suggests that prior knowledge about how an instrument is played may be irrelevant when the mapping strategy uses iconic representation. However, a more thorough study is called for to explore this hypothesis further. A larger sample size would allow for a useful application of more detailed statistical analysis, such as calculating the variance and standard deviation of perceptions. It would also allow for further exploration into the influence of prior musical knowledge on a participant's ability to infer the mapping strategy.

5. CONCLUSIONS AND FUTURE WORK

The GestureChords mapping strategy has been presented, which uses iconic representations of musical conceptual metaphors to provide a transparent mapping of chord selection for freehand gestural control. The strategy has been incorporated in a simple DMI and given a preliminary analysis to test for the mapping's transparency. This pilot study suggests that the mapping successfully provides a transparent mapping for both audiences and performers, and shows promising results for the use of iconic representations of conceptual metaphors in the mapping design of freehand digital musical instruments.

Further developments from this paper will include the development of more complex gestural musical instrument mapping strategies using the iconic representation of conceptual metaphor technique. This will include: exploring note excitation as well as modification, moving away from the reliance on existing instrument metaphors and into pure freehand mapping; applying the technique to dynamic gestural control using continuous movement, allowing for musical expression to be realised in finer detail; and performing further evaluations.

Acknowledgments

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