Rethinking the Transmission Medium in Live Computer Music Performance

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RETHINKING THE TRANSMISSION MEDIUM IN LIVE COMPUTER MUSIC PERFORMANCE

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ABSTRACT

Transmissions require the encoding, communication and decoding of meaningful information across some medium or other. Historically, both the artist and the scientist have tended to treat physical space (and the sound wave in particular) as the medium by which music and sound are transmitted. This paper argues against this conception of the sonic medium and presents an alternative model in which embodied human cognition is treated as the sonic medium. This offers a fuller and more accurate portrait of both transmissions and drift. It allows for the exploitation of the embodied cognitive medium to support the encoding, communication, and decoding of meaningful information to an extent that the physical medium alone does not. It also allows for a transmission to undergo radical drift within the contexts of fashion, genre and cultural situation while retaining its original embodied meaning.

Live computer music performance has, by now, long been dogged by a perceived disconnect between performer and audience. This stems from the lack of transparency inherent to the process of digital sound synthesis. As a result, the audience is often unable to reconcile the actions of a live performer with the sonic result. This need not be the case when one reconsiders the sonic medium in terms of embodied cognition.

Embodied schemata are the basic logical patterns by which we cognize and make sense of our experience. They organise perception, cognition, and action on the basis of recurring patterns of bodily experience. They are of equal relevance from one domain of human experience to the next. Sound and music are cognized and reasoned about in terms of these schemata, as are movement and gesture. It is suggested that this isomorphic relationship allows for a perceptible and intuitive link between the actions of a live computer music performer and the sonic result produced. These recurrent patterns offer us a means of intuitively mapping performance to musical result in the live computer music context.

The authors' work is developing a set of embodied auditory models that organise and map input data in the auditory domain in terms of embodied schemata. These models can be used in performance systems to reflect the embodied meanings of a performance gesture in a sonic result. For example, amplitudes in a piece can be made balance-able by exploiting the "twin-pan balance" schema. Gestures based around the theme of balance are used to define the volumes of concurrent sonic elements. Similarly, legato sweeps can be determined with the "source-path-goal" model, where a starting point, trajectory and end point that are represented in gesture are rendered in sound. Also, looping may be controlled using the "cycle" model, where gestures that determine cycle length map to loop length. Through these models, the basic embodied meanings underlying an input gesture can be transferred to a sonic result making the relationship between input and output increasingly explicit for an audience member. These models are developed and refined on an experimental platform using Csound. However, being logical structures, they can be applied across a wide range of performance systems and technologies. This paper focuses on the development of these models and their use in the context of live computer music performance.

1. INTRODUCTION

There are at least two types of embodiment important to music technology scholarship today. The first is concerned with the role of the body in a technologically advanced music. This trend tends to be directed towards the re-integration of the human body into music performance and interaction through the development of new musical interfaces for gestural control [1]. It has theoretical underpinnings in interaction design and the philosophy of embodiment. The second is embodied music cognition, which draws upon results from cognitive science and empirical musicology in making sense of music in terms of embodied cognitive science. Johnson [2] and Zbikowski [3] are notable exemplars of this approach. This paper is concerned with the latter. The debate between embodied cognition and its chief rival, the information-processing paradigm, will be briefly outlined before chronicling the rise of information-processing in culture, cognitive science, and music. From there, some preliminary results grounded in embodied music cognition that are emerging within the authors' research in auditory display will be offered which may be of relevance for the performance of live computer music.

2. EMBODIED VS DISEMBDOIED COGNITON

The debate between the Embodied and Disembodied (information processing) accounts of human cognition is complex. The embodied camp is composed of a number of inter-related approaches such as situated, enacted, extended and social cognition [4],[5]. At its core, however, exists the common ground of "experimentalism": the notion that knowledge derives from first-hand experience. This point of view is crucial to the arguments presented in this paper. The information processing camp has followed a more linear route from the chaos of introspective structuralism, through behaviourism, to cognitivism, and onward to functionalism via a misreading of Claude Shannon's information theory [6],[7]. Three popular themes define the thinking within this paradigmatic camp:

1. Thought as simple "symbol-manipulation".

2. The duality of mind and body.

3. Positivism.

The treatment of thought as symbol-manipulation (and so mind as computer) has led to the information-processing paradigm being referred to as computationalism in some circles. The duality of body and mind allows for a duality of mental representations (phenomena) and “things in themselves” (noumena). Positivism is in stark contrast to experimentalism as the belief that knowledge can only ever be derived from the logical and mathematical analysis of sensate experience. For most of the 20th century (and earlier still) these disembodied conceptions of the human mind were the scientific and cultural norm in the western world. To this day, they represent the cultural understanding of how scientific enquiry and academic research are to be undertaken.

3. RISE OF THE MACHINES

The rise of the computer itself is not the sole responsible party in the march of the computational theory of mind. Those seeds were sown much earlier. The cognitive sciences have long concerned themselves with classical philosophical questions on the nature of the mind prominent in ancient Greek thought. In 1647, Rene Descartes’ “Meditations on First Philosophy” formalised a mind-body duality that had long been (since the Paleolithic era [8] a hallmark of human culture and religious thought. Where Plato and Aristotle conceived of a surmountable natural disconnect between mind, body and world that was conquerable in the rare heroic case of significant personal effort, Descartes declared an impassable gulf forever severing man from world, and mind from body [9].

Wundt and Titchener’s structuralism was a popular psychological research program at the start of the 20th century. It was rooted in a methodology of experimental analysis of subjectivity, which proved hard to implement empirically [10], and was ultimately a failure. It was harshly criticised by Edmund Husserl [11], who developed his own phenomenological analysis. Husserl’s method was criticised in turn by Heidegger [12], Merleau Ponty [13](1964) and Todes [9]for perpetuating Cartesian dualism and the representational theory of mind [14]. These same themes would find their way into cognitive science through the behaviourist reaction to structuralism. This reaction came about because structuralism failed to generate much empirically verifiable knowledge. Behaviourism favoured the study of *external* behaviours to gain insights into the workings of the *internal* human mind which assumed duality reflected the separated mind and body paradigm.

In the late 1940s, growing dissatisfaction with behaviourism forced scientists to seek answers to the question of the mind from elsewhere, most notably from the newly emerging field of computer science. At the first Hixon Symposium on Cerebral Mechanisms and Behaviour in 1948, to which modern cognitive science traces its lineage, Karl Lashey challenged the prevailing behaviourist attitudes, while John Von Neumann drew striking comparisons between the computer and brain, and Warren Mc Culloch and Walter Pitts paralleled the nervous system with “logical devices”. The scene had been set for a new science of the mind, and information processing was in on the ground floor [6].

As cognitive science was beginning to come together, Norbert Weiner’s “Cybernetics” championed the notion that machines, which exhibited feedback could be described as “striving towards goals”. Parallels were beginning to form between machines and living biological systems. Von Neumann developed the notion of a stored program that could be run on a computing machine, and Claude Shannon showed how logic represents states in electromechanical relay switches [6]. Shannon and Weaver would soon deliver their “Information Theory” [15], while Alan Turing's “Turing Test” [16] effectively reduced the gulf between brain and machine to a simple question of processing power.

Suddenly, the human brain, and so the human mind according to the information-processing paradigm, could be replicated through logical machine-based computation. Unlike that mysterious human mind, logical operations could be precisely measured. A positivistic attitude emerged from this devolution of cognition to simplistic symbol manipulation. If thought was computation, then the human mind was capable of developing authoritative knowledge computationally, in accordance with the positivistic view.

Functionalism was another approach to understanding the mind that arose during this historical period as a reaction against behaviourism. It treats each mental state as a causal link in a larger chain comprised of mental states, sensory “inputs”, and behavioural “outputs”. Functionalism classified mental states on the basis of their function. For example, hunger results from a lack of food which causes discomfort. “Subjective” qualities of mental states fall by the wayside in this model. Heavily influenced by developments in computer science, functionalism was seen as the solution to Descartes dualism. It did away with the role of the body, emotion and imagination in mental life, treating the body (and its physical brain) as the hardware upon which mental software was run [6]. These developments would have a profound effect on another fledgling pursuit of the mid 20th century: computer music.

4. HISTORICAL ROOTS OF DISEMBODIMENT IN COMPUTER MUSIC

Composers who became interested in absorbing the sciences and technologies of the 20th century into their work may have run the risk of absorbing much of the information-processing paradigm and positivism along with them. However, music did not become disembodied with the advent of computer science alone. As with cognitive science disembodiment in music it finds its root in ancient Greek thought. A chronicle of the entire history of disembodiment in music from ancient Greek thought to Computer music is far beyond the scope of this paper. An overview of the trend towards disembodiment in Western art music is sufficient.

In 1618, Descartes drew a strict division between the formal mathematical and physical elements of music, and its more subjective emotional counterpart which he characteristically considered less worthy of true scientific review [17]. Descartes musical writings may not have been revered but his philosophical thought heavily impacted the aesthetic theory of Immanuel Kant. Kant, having absorbed this duality, reduced art, beauty and music to a (positivistic) aesthetic formalism and proposed a general transcendental aesthetic as well as logic [18].

This trend is seen continued in Schopenhauer who thought of music as a disembodied manifestation of “noumenal” (as opposed to phenomenal) reality, simply serving to re-enforce the duality between the noumenal object and phenomenal subject [19],[20]. This, disembodied view influenced composer Richard Wagner [21] who would conceive of his own compositional process through Schopenhauer's lens. He would in turn pass this on to Arnold Schoenberg [22] whose 12-tone compositional technique expanded Wagner's Hauptmotife with an emphasis on positivistc formal rules that retained the subject-object dualism inherent in Schopenhauer. The Darmstadt School inherited and expanded the 12-tone technique through Anton Webern and Pierre Boulez to create a more idealistically "democratic" compositional system termed serialism (Grant 2005, Luciani 2009). By the mid 20th century Western art music existed within a positivistic and disembodied paradigm.

It was into this atmosphere during the 1940's that Pierre Schaeffer introduced his Musique Concréte. This compositional approach was embraced, at least in part, by influential Darmstadt composers like Pierre Boulez, Jean Barraqué, Edgar Varése, Karlheinz Stockhausen and Iannis Xennakis. Schaeffer was fascinated with Edmund Husserl, and borrowed the epoché method from his phenomenological analysis. This was a method for investigating the "essence" of phenomena by suspending judgement about the objective world of which subjective phenomena were thought to be representations and paying attention only to the phenomena itself. Schaeffer suggested a mode of listening called "reduced listening" in which sounds were decoupled from assumed objective sources in this way. These sounds were termed Object Sonore [25]. The entire field of acousmatic (meaning: "behind the veil") music would grow from this methodology. In order to compose with the reduced acoustic event the early proponents of Musique Concréte recorded "real-word" sounds to magnetic tape. The tape could then be manipulated through a series of techniques such as cutting, pasting, looping, reverb, speed manipulation, and eventually overdubbing, in order to effect the original sound object. These groundbreaking techniques and technologies, were researched at Schaeffer's Groupe de Recherches Musicales (GRM). They have imparted a set of concepts for the recording and manipulation of sound based on the acoustic event paradigm that shaped both the analog and digital music technologies of the 20th century and are prevalent to this day [26]. Schaeffer's acoustic event paradigm has been faithfully and deliberately perpetuated and now shapes the modern music technology landscape [27].

5. FORMULATING THE PROBLEM

Modern computer music is composed mainly using techniques and technologies that were developed for a disembodied representational mind that exists in a positivistic world. These conceptions of both mind and world have been criticised heavily by, in philosophy: Heidegger [12], Merleau Ponty [13], Todes [9], in cognitive science: Johnson [28], Varela et al. [4], Núñez & Freeman [29] Lakoff & Johnson [30], Fauconnier & Turner [31], and in musicology: Zbikowski [3], Leman [32], Godoy & Leman, [1]. These thinkers suggest that the mind is embodied and support an "experientialist" worldview.

Compositional and performance tools for live computer music draw heavily from the conceptual apparatus of Schafer's Object Sonore. This paradigm actively seeks to decouple the acoustic event from it's assumed source. Live computer music performance is faced with a "schizophonic" divide [33] between performer and audience arising from the technological decoupling of musical effect from physical cause [34],[35]. This has lead to a situation where, for the audience, the actions of the performer are often irreconcilable with the music performed.

It has been suggested that this gulf may be bridged within an embodied cognition context through the relation of musical gesture to performance gesture [36],[32],[1]. Standard human computer interaction is based around office gestures that have not proven useful in bridging this gap [37]. Tangible music controllers that make use of complex mappings [38] to satisfyingly re-embody the performer in the live context are called for [1].

Within the embodied paradigm listeners make sense of music through the sensorimotor mimesis of embodied schemata [28], cross-domain mappings [30],[31] metaphorical extensions [30] and conceptual blends [31]. These provide a new conceptual framework within which to address the gulf between performer and audience in live computer music by linking performance gesture to musical result in a way that makes sense to the embodied mind. Embodied schemata are recurrent, gestalt-like, organisational frameworks found in daily life that are foundational to the embodied mind. Through cross domain mapping the mind makes sense of experiences and thought in terms of these embodied schemata. Conceptual metaphor allows the mind to understand one concept in terms of another while blending merges two or more concepts together to create new concepts. There is a growing body of empirical work demonstrating how gesture can be coherently mapped to sound and music using these embodied cognition principles [39],[40],[1].

6. MAPPING PROBLEMS IN SONIFICATION

In standard parameter mapping sonification practice dimensions within a data-set are mapped to salient auditory dimensions such as pitch, amplitude, tempo etc. Auditory dimensions however are neither orthogonal nor linear. Perceptual entanglements exist between seemingly independent dimensions. For example, pitch is dependent on amplitude and spectral shape and amplitude is non-linear as described by equal loudness contours. These entanglements and non-linearities present a large problem for perceptually valid mapping in sonification [41],[42]. It has been argued that the parameter mapping problem is a result of the disembodied and positivistic technological tools and techniques that the sonification field has borrowed from computer music [43].

The research presented and discussed in the following sections explores ways of reducing the amount of learning required for understanding of an auditory display by leveraging "non-symbolic" meaning. Mapping models that emphasize embodied structures within the data are being developed to achieve this. Data is mapped to multiple synthesis dimensions, as organised by the embodied mapping model, in order to provoke a cognitive effect. This top-down approach works with the entanglements and non-linearities of the auditory system. It conveys data within the constraints of a larger organisational structure, instead of directly mapping it to supposedly individual auditory dimensions. It is planned to extend these mapping models to the mapping of performance gesture to musical gesture in a live computer music context.

7. DESIGN PARADIGM

The approach adopted here follows that suggested by Imaz and Benyon[44] for the use of embodied cognition frameworks for design of HCI systems at the "human scale". In brief, the approach requires a designer to think in terms of conceptual networks of input, generic and blended spaces where embodied schemata (inclusive of perceptual content), cross-domain mappings, frames and conceptual metaphors provide inputs, and from which the users' understanding of the interface emerges [30],[31]. This analysis is applied across an interface from a global scale (of the interface in its entirety) down to a local scale (of groupings and sub-groupings of features). Interfaces are designed to adhere to the rules of blending, cross-domain mapping, conceptual metaphor, and embodied schemata.

8. REAL TIME EXAMPLE:TIWN-PAN BALANCE

A simple model for mapping real-time data to audio has been developed. It organises auditory elements using the "Twin-Pan Balance" schema [28] framework (Figure 1). It is based around the embodied metaphor of a "weighing scales", an extension of the central schema which "balances" two sound sources around an axis. The model accepts a single input X. An inverse -X is also represented. Both values are then mapped to a group of parameters in FoF synthesis that convey height, weight and distal cues. The auditory scene consists of two tones presented at equal distance from one another in a stereo plane.

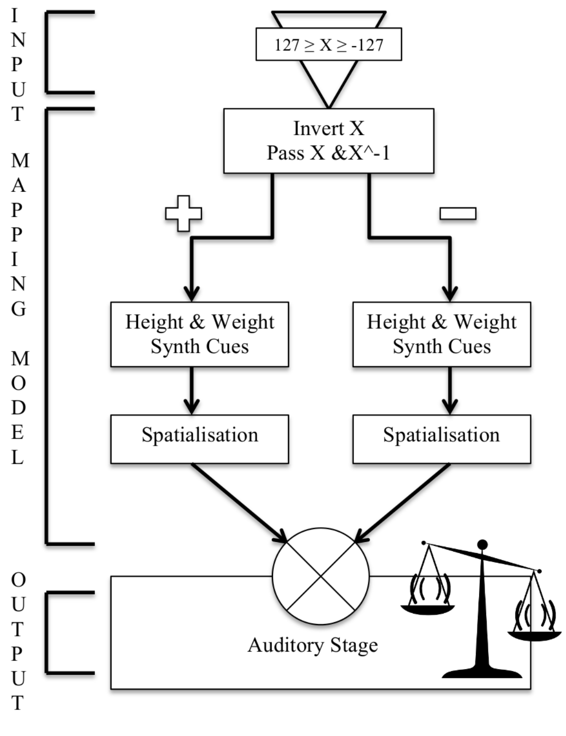

Figure 1: Twin-pan Balance Mapping Model

9. EARLY RESULTS

This simplistic mapping model has been employed on multiple real-time software systems developed in Csound. Preliminary usability testing has been carried out with both GUI input onscreen (a representation of a simple knob), and using hardware prototypes employing MIDI controller pots. This mapping model has been applied to FoF synthesis techniques. Preliminary usability testing has shown positive results.

An informal evaluation methodology has been used to gather feedback on the system. Some users were presented the display on stereo speakers, and others using earphones. Users were encouraged to think aloud during evaluation as well as ask any questions that came to mind. They were given a short questionnaire to answer also.

Users were asked to draw inferences from the display about two variables A and B represented in the auditory scene. The state of the display was varied over the course of each test with users being asked the following questions:

Questions	Assertions in the Literature
Which is higher A or B?	Amount is Verticality
Which is more valuable A or B?	Value is Size
Which is Heavier A or b?	Amount is Weight
Which is more Important A or B?	Comparison is importance of weighting, Up is important, Central is Important
Which is there more of A or B?	Amount is Size, Amount is Verticality, More is Higher
Which is better A or B?	Up is Good,More is Better
Is A or B good?	High is Good, Up is Good, Up is High
Is A or B true?	Up is true
Which stimulus relates to happiness?	Happy is up, Happy is More
Is the system in balance?	Comparison of properties is comparison of physical properties.

Table 1:Twin-pan Balance Questions

10. ANALYSIS

The aim of this testing is to determine if people apply meaning to auditory phenomena in the way predicted by the literature. The results of these tests generally tended to coincide with the embodied cognition literature. This was an extremely simplistic experiment but a necessary first step in determining the merit of this approach. The questions posed during testing were derived from the literature on metaphor, cross-domain mapping and embodied schemata. [28],[45],[30]. The testing involved in the "Up-Down" schema as well as the "Twin-Pan Balance" schema. Numerous other schema are complicit in the make-up of any one schema. Schema are organisational structures and so contain substructures within their own make-up.

This mapping model lends itself well to the simultaneous manipulation of two discrete sonic features, as in, for example, the manipulation of amplitudes or pitch across two sonic objects. Our instantiations have focused on the inverse manipulation of amplitude and frequency and, more interestingly, grain rate and size in FOF synthesis. To date these manipulations have been carried out using GUIs and MIDI controllers. The mapping model will be extended to systems that handle direct gestural input for live computer music performance. An area of interest for further exploration is the counter-balancing of opposed musical elements across multiple sound events. For example, frequencies in one sound object vs. spectral content in another. It is hoped that such couplings will aid the artist in creating new musical unities that operate outside of the event paradigm by developing unities between musical features traditionally conceptualized as elements of distinct and separate musical events.

This model was developed for exploratory purposes. It was not used to evoke any specific meanings or to communicate explicit data-relations. It was used to determine if sonifying real-time data with an embodied mapping model could evoke the intuitive meanings suggested by the literature.

11. NON-REALTIME EXAMPLE: CENTRE-PERIPHERY

This model was designed to communicate specific meanings inherent in a data-set. Based chiefly on the internal logic of the centre-periphery schema (Figure 2) it is still in active development. An early version was demoed at the 2013 ICAD conference [46]. The model has been used to sonify weather data.

The mapping model establishes a sonic framework in the auditory scene that is governed by the logic of data-relevant embodied schemata. It then represents quantitative data transformations through the modulation of qualitative elements within the auditory scene in accordance with the logic of the overall framework. This should make for a display that is at once intuitive and informative and operates at a "human scale" [44].

In the case of this specific sonification the "probability of rain" over the course of a week is represented through the modulation of a relevant auditory icon along the distal dimension. This makes use of the central image schemata and its metaphorical extensions in conveying data to the listener. As the "rain" proceeds towards the listener, the probability of rain increases. There are two data measures involved: the probability of rain and the passage of time. Both can be related through the modulation of dimensions within a qualitative signifier (a sonic representation of the qualitative aspect of a data point, in this case a rain storm to represent rain) in the auditory display. However, the second measure "time" is of a qualitatively different type, and our conception of it is often structured by the source-path-goal schema [28],[30]. As such, time should be mapped in accordance with this schema. This is achieved by using amplitude envelopes so that the audio fades in to represent the start of a day (source), holds steady for the length of the day (path) and fades out to represent its end (goal).

There are three spaces to be considered in the development of embodied mapping models for auditory display: the data-space, the embodied cognitive/perceptual auditory space, and the synthesis space. As such, the mapping model for this example can be expressed as follows:

1. Elements in the auditory scene are organised, for the duration of the sonification, using the "Centre-Periphery" schema. The logic this schema is transposed to the auditory scene, sonic elements must abide by it's logical rules.

2. Probabilistic (Quantitative) data is expressed through the modulation in distal cues of an auditory icon (representative of qualitative data) according to the logical rules of the centre-periphery schema.

3. Temporal (Qualitative) data is expressed through the modulation in amplitude of an auditory icon (representative of qualitative data) according to the logic rules of the source-path-goal schema.

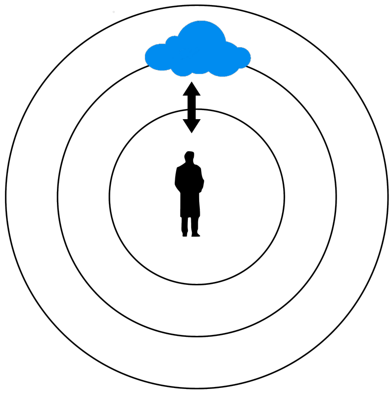

Figure 2: Centre-periphery Schema

12. EARLY RESULTS

The model was subject to the same informal evaluation as the previous model. Participants are told that what they are hearing is forecast of the probability of rain over the period of one week. The questions were designed to determine if the sonification had imparted an understanding of the original data-set and also what "kind" of meanings were being communicated. The data points to be related were "chances of rain" correlated to "days of the week". The aim is not to communicate exact numerical values to the user. A simple verbal or written account is much better suited to that task. The aim is to communicate embodied meanings inherent to the data in ways that require minimal previous learning from the user. The following questions were asked of evaluators:

Questions:	**Testing for:**
Does the display express chances of rain well?	Days of the week data.
Does the display express chances of rain well?	Probability data.
What is the rain forecast like for the week?	Both data points together.
When is it most likely to rain?	Both data points together.
When is it least likely to rain?	Both data points together.
When is there an equal chance of rain?	Both data points together.
Do you understand the data being conveyed?	Both data points together.
How would describe your understanding of the data?	General Feedback
How would you make the display more effective?	General Feedback

Table 2: Centre-periphery Questions.

This model has been tested on both a stereo speaker arrays and using a stereo headphone set-up. Evaluators could generally determine which days carried a strong, weak or even probability of rain. Outside of these ranges they found it hard to determine. In earlier iterations, techniques borrowed from auditory graphing for marking the passage of time were pointed out as inadequate. The technique used timely recurrent "blips" to establish an axis through time. This approach was rejected and instead amplitude envelopes described in the previous section were used to represent the passage of day into night. The data for the sonification is the following:

Day	Chances of Rain
Monday	50.00%
Tuesday	75.00%
Wednesday	20.00%
Thursday	45.00%
Friday	100.00%
Saturday	10.00%
Sunday	30.00%

13. ANALYSIS

As mentioned the point of the evaluation was not just to see if the display worked but to uncover what "kind" of meanings the display conveyed to the user. Evaluators communicated a strong sense of understanding the "important points" of the data. Although they couldn't discern the exact numerical probabilities, this did not hinder them from achieving an in depth knowledge of the weeks rain patterns. They could recount likelihood of rain for each day with ease after just one listen. They reported an understanding that was neither numerical nor linguistic but a more intuitive or "felt" understanding. This type of "non-symbolic", "felt" or "embodied" understanding is discussed at length in the embodied cognition and embodied philosophy literature [2], [44]. It is said to supply the working knowledge by which one makes sense of their world [3] as well as offer a meaningful grounding for symbolic data [30]. Embodied mapping models can be used to convey the intuitive embodied meanings within a data set as opposed to symbolic meanings mediated by language and numeracy.

Flowers [47] points out that in auditory display it is often best to allow time to represent time. In representing time within the display, the scale was "compressed" [31] from seven days to a matter of seconds. As mentioned different methods for notating the passage of days were tested. The source-path-goal amplitude envelope method method was chosen for its cohesion with the syntax of auditory display already established. It made sense at the human scale where the "bleeps" method evidently did not. Where this method introduced a new "sonic object" and conceptual space to the auditory display, the fading technique is a simple modulation of conceptual elements already present in the display.

The mapping model is built around the "Centre-Periphery" schema which also employs the "Near-Far" schema.The metaphorical extensions of that schema which are leveraged int this sonification are:

1. Importance is Centrality.

2. Comparison of States in a Dynamic Situation is Comparison of Distance.

It is important to note that the second metaphor is not explicit to the "Near-Far" schema. The "Source-Path-Goal" structuring used in the sonification of temporal data here could easily be transposed to the live computer music environment for the mapping of similarly structured gestures (start point, trajectory and end-point) to acoustic features. One obvious application is in legato playing. However, the structuring of envelopes in synthesis parameters across multiple sound sources in order to create sonic unities that subvert the acoustic object paradigm might be of greater interest to contemporary research.

14. DISCUSSION

The approach here presented differs from standard methods in parameter mapping sonification. The mapping model establishes a sonic framework in the auditory scene governed by the logic of data-relevant embodied schemata. Sonic signifiers of the qualitative data types are organised within this framework. With this set-up in place quantitative data can be expressed through the modulation of the qualitative sonic signifiers. This system assumes that quantitative data are measurements of some qualitative data type. Due to this it precludes the expression of abstract numerical values as discussed earlier. Instead it offers an intuitive wholistic understanding of a data-set that requires minimal previous learning from the user.

More mapping models of this type are required before an advanced implementation could be designed for computer music control. This approach, however, seems promising and will be extended to develop mapping models that blend the "Cycle" schema into auditory display and computer music interfaces. Being implicit in our reasoning in regards to cyclical processes it could prove a good candidate for linking gesture to looping functions within a performance system.

The need for a method that links musical result to performance gesture in accordance with the requirements of an embodied audience. It has been suggested that this may come from systematic musicology [48] where a body of working describing musical structure [3] and musical gesture [1] in terms of embodied cognition principles is emerging. The research presented here draws from a HCI framework [44] because the work is is in the field of sonification and auditory display. This framework is wide enough to encompass concepts from embodied musicology into the design of new mapping models.

The evaluation of the first mapping model discussed in this paper makes a case for the utility of embodied schemata as organisational structures for auditory display and computer music interfaces. The evaluation of the second mapping model illustrates the "kinds" of intuitive meanings that can be conveyed to a user through these models. The connotative nature of these meanings closely resembles those specified by Leonard Meyer [49] as "musical meanings". As such models of this type can be of value in overcoming problems stemming from historical disembodiment in both sonification and live computer music performance.

The communication of non-symbolic meaning through embodied mapping models represents a new departure in the field of sonification. Non-symbolic auditory meaning has long been considered a purely musical endeavour. Thanks to the advances in cognitive science over the past 20 years, embodied meaning, long a domain of pure music, can now be harnessed within the field of sonification. The same mapping strategies used in sonification can provide a basis for the re-embodiment of the computer music performer in the live context. The gulf between performer and audience is a result of an overly disembodied and positivistic understanding of sound and music. It may using embodied mapping strategies that link structures of gestural performance to sonic features in a familiar and intelligible manner. Future research intends to explore these possibilities more thoroughly.

15. CONCLUSIONS AND FURTHER WORK

After a brief definition of the embodied and information-processing paradigms for cognition, this paper presents disembodiment in computer music in its historical context by highlighting relationships between developments in music and cognitive science as well as popular philosophical issues. It then explores some of the problems facing the live performance of computer music today as a result of this disembodiment. It is suggested that a solution may be found by taking into account the embodied nature of the audience and designing systems for live performance with embodied principles in mind. Some contemporary work being undertaken in the field of auditory display and sonification is then presented and it is suggested that the mapping models being researched and developed could be extended to the performance of live computer music as a means of linking gesture and musical discourse at the human scale. Future work will focus on the development of more mapping models using the techniques discussed in this paper. Applications of these models in the context of live computer music will also be explored.

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