Musical Creativity on the Conceptual Level

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Abstract. The theory of conceptual spaces, a geometrical form of knowledge representation introduced by Gärdenfors [1], is examined in the context of the general creative systems framework introduced by Wiggins [2, 3]. The representation of musical rhythm and timbre on the conceptual level is then discussed, together with software allowing human users to explore such spaces. We report observations relevant for future work towards creative systems operating in conceptual spaces.

Key words: Creative systems framework, conceptual space, geometrical representation, music

1 Introduction

Wiggins [2, 3] provides the Creative Systems Framework (CSF) for describing and reasoning about creative systems, based upon the work of Boden [4]. The CSF defines a creative system as 'a collection of processes, natural or automatic, which are capable of achieving or simulating behaviour which in humans would be deemed creative' [2, p. 451].

As an abstract framework, the CSF raises many practical issues. Here we consider representation, both in terms of creative artifacts, and the search spaces in which they may be discovered. We draw on the theory of conceptual spaces proposed by Gardenfors [1], in which concepts are represented in geometrical space. In the following sections we summarise both the CSF and theory of conceptual spaces, before examining how they may fit together in the context of music.

1.1 Creative Systems Framework

The CSF defines a number of symbols and functions, in particular:

$\mathcal{U}$	The universe of all possible concepts
$\mathcal{R}$	Rules defining valid concepts
$[\![\mathcal{R}]\!]$	An interpreter for $\mathcal{R}$, tests the validity of individual concepts
$\mathcal{C}$	A conceptual space, a set of valid concepts selected by $[\![\mathcal{R}]\!]\mathcal{U}$
$\mathcal{T}$	A traversal strategy for locating concepts within $\mathcal{U}$
$\mathcal{E}$	Rules which evaluate the quality or desirability of a concept
$\langle\langle \mathcal{R}, \mathcal{T}, \mathcal{E} \rangle\rangle$	An interpreter for $\mathcal{T}$, informed by $\mathcal{R}$ and $\mathcal{E}$. It operates upon an ordered subset of $\mathcal{U}$ (of which it has random access) and results in another ordered subset of $\mathcal{U}$.

We should be careful to distinguish membership of a conceptual space from *valued* membership; for example, we might recognise a concept as conforming to the syntactical rules of a limerick but not be funny. Accordingly, $\mathcal{R}$ governs membership of concepts to the limerick class, whereas $\mathcal{E}$ enables value judgements to be made over these concepts.

Creative systems search for valued concepts by iteratively applying $\langle\langle\mathcal{R}, \mathcal{T}, \mathcal{E}\rangle\rangle$ over a set of concepts. Given a $\mathcal{C}$ with $\mathcal{E}$-valued yet undiscovered concepts, the likelihood of success depends entirely on the ability of $\mathcal{T}$ to navigate the space. However, a crucial feature of the CSF is that creative search is defined as an operation over $\mathcal{U}$, and not limited only to $\mathcal{C}$. This allows for the possibility of the search leading *outside* $\mathcal{C}$, in that the application of $\mathcal{T}$ results in concepts that do not conform to $\mathcal{R}$. Such effects are termed *aberrations* and invoke *transformational creativity.* If an aberration contains only $\mathcal{E}$-valued concepts then we have *perfect aberration* and $\mathcal{R}$ should be transformed to include the concepts in $\mathcal{C}$. If none of the concepts are valued then we have *pointless aberration* and $\mathcal{T}$ should be transformed to avoid them in the future. If some are valued and others not, then we have *productive aberration* and both $\mathcal{R}$ and $\mathcal{T}$ should be transformed. In this way, a creative system is able to dynamically manipulate both the space it is searching and the manner in which it searches in response to the concepts it finds.

1.2 Conceptual Spaces

Wiggins' high-level specification of the CSF deliberately excludes discussion of implementation. To partly address this regarding $\mathcal{C}$, we draw on the geometrical theory of conceptual spaces proposed by Gardenfors [1]. Despite employing the same terminology, a conceptual space in the CSF denotes an abstract component of a creative system ($\mathcal{C}$), and should not be confused with the conceptual spaces theory of representation.

Gardenfors [1] argues that concepts should be represented using geometry on what he terms the *conceptual level.* This level of representation is situated between the *symbolic level*, including for example formal grammar, and the *subconceptual level* of high dimensional representations such as neural networks. These three levels of representation should be understood as complementary.

To summarise Gardenfors' theory of conceptual spaces, we begin with the notion of similarity represented as distance, allowing models of cognitive behaviour (such as creativity) to use tools from geometry to represent and manipulate concepts. Similarity is measured within *quality dimensions*, which 'correspond to the different ways stimuli are judged to be similar or different' [1, p. 6]. An archetypal example is a colour space with the dimensions hue, chromaticism, and brightness. Each dimension has a particular geometrical, topological or ordinal structure. For example, hue is circular, whereas brightness and chromaticism correspond to measured points along finite scales. Identifying the characteristics of a dimension allow meaningful relationships between points to be derived.

Related dimensions are grouped into *domains.* A domain is a set of *integral* (as opposed to *separable*) dimensions, meaning that a value cannot be attributed in one dimension without every other dimension in the domain also taking some value. Therefore hue, chromaticism, and brightness in the above model of colour form a single domain. It then follows that the definition of a conceptual space is simply: 'a collection of one or more domains' [1, p. 26].

In a conceptual space, similarity is directly related to proximity. Such spatial forms of representation naturally afford reasoning in terms of spatial regions. For example, in the domain of colour, it is possible to identify a region of the space that corresponds to the colour *red*. Boundaries between regions are fluid, which is an aspect of the representation that may be usefully exploited by creative systems searching for new interpretations of familiar concepts.

Gardenfors identifies various types of regions with differing topological characteristics. *Convex* regions are highlighted as being of particular importance:

CRITERION P A *natural property* is a convex region of a domain in a conceptual space. [1, p. 71]

Taking again the example of *red* in the domain of colour; if we consider any two shades of *red*, any shade between them would also be *red*. Therefore, the region corresponding to *red* must have a convex shape. Convex regions in conceptual domains can be closely related to basic human perceptual experience. In the context of creative systems, having such information embedded within the structure of the knowledge representation may potentially simplify processes of creative and inductive inference, and possibly contribute to the discovery of more highly valued artifacts.

For relatively straightforward domains such as colour, we can think of concepts as natural properties. However, more complex concepts may exist over multiple domains. Gardenfors thus defines a concept as:

CRITERION C A *natural concept* is represented as a set of regions in a number of domains together with an assignment of salience weights to the domains and information about how the regions in different domains are correlated. [1, p. 105]

Our interpretation of CRITERION C is that a natural concept is a set of one or more natural properties with salience weights.

2 Discussion

To aid our discussion we introduce the following to differentiate between three levels of representation:

^{s} Symbolic level
^{c} Conceptual level
^{sc} Sub-conceptual level

Each suffix may be applied to an appropriate set symbol in order to make explicit particular subsets of elements according to the level of representation. For example, a subset of symbolically represented concepts in a conceptual space $\mathcal{C}$ would be denoted $\mathcal{C}^s$, and the rules specifying this subset denoted $\mathcal{R}^s$. The ability to explicitly refer to concepts with different representational properties helps clarify the situation where multiple levels of representation are available in $\mathcal{C}$. For example, in §3.1 we introduce a $\mathcal{C}$ comprising of both $\mathcal{C}^s$ and $\mathcal{C}^c$ subspaces.

We define the structure of the conceptual level, as described by Gardenfors [1], with the following symbols:

- $\mathcal{D}$ Domain, a set of one or more integral dimensions
- $\mathcal{P}$ Convex region within $\mathcal{D}$
- $\mathcal{C}^c$ Set of $\mathcal{P}$, with salience weightings
- $\mathcal{R}^c$ Rules defining $\mathcal{C}^c$

Our definition of $\mathcal{C}^c$ only includes search spaces which adhere to CRITERION C. There may be creative situations requiring a looser definition, but for the purposes of this paper we only consider spaces adhering to the strict constraint of convexity.

For example, in a search within $\mathcal{P}_{red}$, the search space $\mathcal{C}^c$ would begin as the region of all possible reds within $\mathcal{D}_{colour}$. Transformational creativity is unlikely to modify a property as perceptually grounded as $\mathcal{P}_{red}$. We may however imagine other properties, for example the musical genre 'drum and bass', fluid enough to be transformed during a creative process. We posit that whether transformations of a search space $\mathcal{C}^c$ can modify natural properties depends on some perceptual *groundedness* weighting of the instances of $\mathcal{P}$ concerned.

The motivation for viewing creativity on the conceptual level becomes particularly clear when considering traversal in the CSF. Here creative search is literally spatial, where $\mathcal{T}$ gives *vectors* from input concepts to output concepts. Each vector itself has meaning; for example, representing a perceived *lightening* or *warming* in $\mathcal{D}_{colour}$.

Where a vector is taken outside of a $\mathcal{P}$ we have an aberration. If valued concepts are thus found, the creative system may adjust the size, shape and/or location of $\mathcal{P}$ to include them. If the region is extended outwards, preserving convexity, new concepts between the aberration and the previous $\mathcal{P}$ will be included. This amounts to an inference that if aberrant concepts are valued, then the concepts along a path to them are also likely to be fruitful in a search. Aberrant discoveries may also lead to new domains being incorporated or excluded from the search, as a further example of transformational creativity.

A key hypothesis from Gardenfors is that 'a metaphor expresses an identity in topological or geometrical structure between different domains' [1, p. 176]. We may formally specify metaphor as a mapping of a $\mathcal{P}$ from one $\mathcal{D}$ to another. For example, by taking $\mathcal{P}_{warm}$, in a $\mathcal{D}_{temperature}$ and mapping it to the alternative $\mathcal{D}_{colour}$ we have constructed the metaphor 'a warm colour'. Gardenfors [1] presents such metaphorical constructs as central to semantics. He argues meaning is better represented in spatial relationships on the conceptual level, rather than grammatical syntax on the symbolic level. Indeed he describes the mapping of a $\mathcal{P}$ to a new $\mathcal{D}$ as creative [1, p. 179].

3 Musical Applications

We present two prototypical conceptual spaces that may be explored by human users. We have not attempted to implement any operations on the space that might be deemed creative; this is left for future work. Our SuperCollider3 software, together with in-browser demos, is available in the on-line appendix [5]. We have modelled conceptual spaces with quality dimensions in order to explore possible musical applications, and make no claims at this stage as to the precise relationship between the models and human perception.

A conceptual space of music could take many forms, differing considerably in scope, complexity and perceptual groundedness. We focus on two aspects of music: rhythmic structure and percussive timbre. Each aspect involves different levels of musical and representational abstraction. Although necessarily reductionist, the treatment of each aspect reveals complementary insight into issues of building models in conceptual space. The rhythm space is constructed by recourse to concepts of music theory, while the timbre space draws from empirical studies of timbre perception and utilises a physical model of a drum membrane.

3.1 Rhythm Space

London [6, p. 4] defines rhythm as involving ‘patterns of duration that are phenomenally present in the music’. Duration here refers not to note lengths, but to the *inter-onset interval* (IOI) between successive notes. Rhythm is therefore a theoretical construct describing the arrangement of events in time. However, this objective description does not necessarily accord with perceived musical structure. The perceptual counterpart to rhythm is metre:

> [M]etre involves our initial perception as well as subsequent anticipation of a series of beats that we abstract from the rhythmic surface of the music as it unfolds in time. In psychological terms, rhythm involves the structure of the temporal stimulus, while metre involves our perception and cognition of such stimulus. [6, p. 4]

The importance of listener perception in the creation of musical experience in part explains the prevalence of algorithmic methods in composition. However, when such methods are simply executed by computer, it is difficult to argue for creativity on behalf of the system. Much of the work of a human composer concerns selecting or developing compositional techniques, informed by an anticipation of how the resulting music might be experienced by an audience. Within a shared framework of reference, both audience and composer comprehend new music in relation to previous musical experience—further emphasising the role of similarity in creativity, as well as in wider cognitive behaviour [7].

Our prototypical search space of rhythm $\mathcal{C}_{rhy}$ consists of a conceptual representation of rhythmic structure $\mathcal{C}^c_{rhy}$, together with a symbolic representation of timbre $\mathcal{C}^s_{rhy}$. The domain of rhythmic structure $\mathcal{D}_{rhy}$ is a discrete space existing in three dimensions. Within $\mathcal{D}_{rhy}$ we can identify a convex region $\mathcal{P}_{rhy}$

as the particular rhythmic property of interest to our search. Therefore, $\mathcal{P}_{rhy}$ constitutes the entire conceptual search space $\mathcal{C}^c_{rhy}$. For the present purpose, $\mathcal{P}_{rhy}$ corresponds to the property of metrical salience, described below. This very constrained notion of rhythmic structure is chosen in order to create a readily comprehensible space of rhythmic possibility, and is in no way intended as a general model of musical rhythm.

$\mathcal{P}_{rhy}$ is shown as the filled region in Figure 1d. The gray-scale level in each of the diagrams in Figure 1 represents metrical salience, and thus visualises the notion of similarity that pertains to proximate points in the space. Unlike Gardenfors, who allows variable salience weightings for each dimension, here they remain fixed, effectively defining symmetrical distance (similarity) between any two points in the space. The precise value of salience weights is not addressed here, but as an observation, the weighting of the x dimension should be greater than that of y, because changes in x affect a greater change in rhythmic structure (in terms of metric salience) than changes in y.

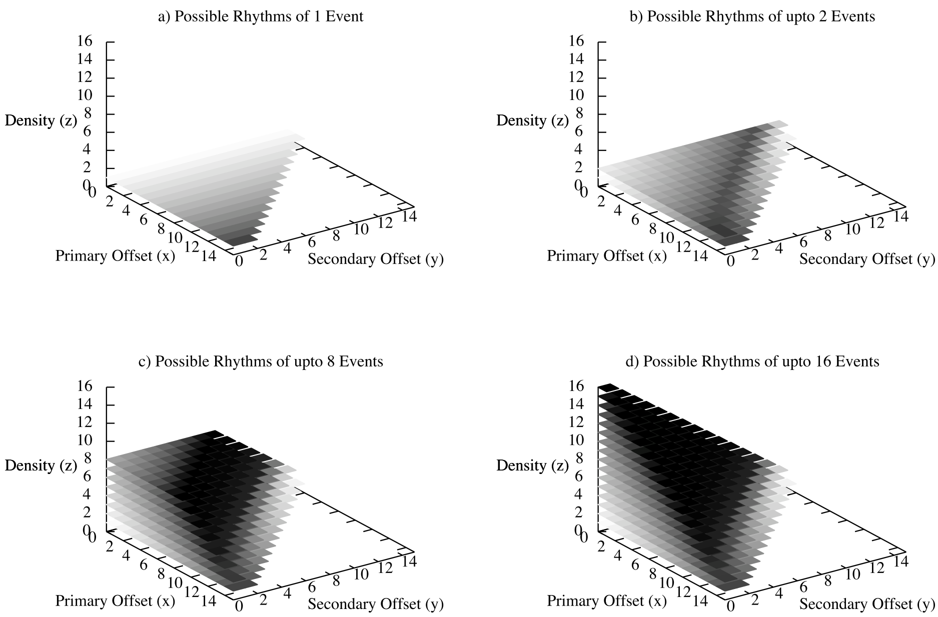

Fig. 1. Rhythm Space

A symbolic representation of timbre considerably simplifies the search space of rhythm. Musical notes are considered atomic sound events of predetermined timbre and duration. Both these features are represented by labels corresponding to types of percussive instruments; for example, `kick-drum`, `snare-drum`, and `hi-hat`. This simplification allows for the complexities of timbral perception to be excluded from the model, while allowing for the representation of polyphonic rhythms, as is idiomatic of drum-kit performance.

The rationale behind the specification of $\mathcal{D}_{rhy}$ draws on concepts from music theory. Both Western and non-Western theories are pertinent here, but given the relative simplicity of Western conceptions of rhythm compared with some non-Western counterparts, we focus on the former. Western music theory is a body of knowledge accumulated over a considerable period, closely bound to conventions of notation, which in turn are closely bound to the pragmatic concerns of performance and composition. In order to communicate musical ideas effectively, music theory arguably has some claim to perceptual validity. However, future work on conceptual spaces of rhythm should seek to incorporate empirically grounded research from fields such as music psychology and cognition.

Of specific interest to rhythm and metre, music theory provides useful concepts such as bars, tempi, time signatures, and a system of rhythmic structure based primarily on the equal division of units of time. Each point in the rhythmic domain corresponds to a single bar-length rhythm. Each bar is the same predetermined duration, relative to the current tempo, which is specified in beats-per-minute (bpm). Each bar contains four beats, subdivided by two or four, resulting in a sixteen-step pattern—a familiar concept in much electronic dance music. It is important to note that each point in the space corresponds to a bar-length rhythm performed on a single percussive instrument (represented by a symbol on the symbolic level). Therefore, a polyphonic rhythm comprising multiple rhythmic parts is represented by a set of points in the rhythmic space.

Theories of musical metre typically concern cyclic patterns of strong and weak beats. Within our constraint of four beats-per-bar, and simple beat divisions, a common interpretation of metrical salience would give more weight to the first and third beats of the bar, followed by beats four and two. The weightings of subdivisions of beats are less well defined, and arguably, strongly genre dependant. However, as a default for sixteen steps, we chose the following weightings:

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[16, 1, 9, 5, 13, 3, 11, 7, 15, 2, 10, 6, 14, 4, 12, 8]
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Describing $\mathcal{D}_{rhy}$ in more detail, the `density` dimension (z in Figure 1) simply corresponds to the number of events to be played in a bar by a specific instrument. New rhythms are created by adding or removing events. Within individual parts, events are added to the bar at the position with the highest metrical weighting not already occupied by an event, or designated a rest. Events are removed from the bar in the reverse order.

The x and y dimensions control the process of rhythmic elaboration that determines *where* events are placed in the bar. This is achieved by constraining the articulation of metrically salient positions in the bar. As x increases, the next most salient metrical position is designated a rest. Any currently existing events in that part are shifted to positions of less metrical weight. The process is reversed as the value of x decreases. Changes in the y dimension have a similar effect, except that the position of a rest is calculated relative to x. If metre is thought of as layered cyclic patterns (as discussed by London [6]), x and y effectively diminish the emphasis of lower-order metric cycles. The effect of increasing x and y could loosely be described as decreasing metrical stability, and in particular areas of the space, strong syncopation. The perception of metre is more complex for polyphonic rhythms, as different instruments may emphasise different metrical points.

Although anecdotal, it is possible to draw some useful observations from simply exploring the rhythm space. Navigating the space in real-time can be a stimulating musical experience, but one that is relatively short-lived unless greater musical interest is intentionally sought. This can be achieved by finding particularly unusual or complex rhythmic patterns, or by employing higher level concepts of musical structure. A simple technique for creating a sense of larger-scale structure is to jump to a very dissimilar region of the space at regular intervals, thus breaking the established rhythm in the manner of a drum-fill.

Given the constraints of the space, it is unsurprising that additional concepts are necessary in order to sustain musical interest. This raises several implications for future artificial agents that might explore this space. Firstly, in order to avoid mundane rhythmic patterns, agents should possess the evaluative ability to detect some measure of complexity or novelty in discovered rhythms with respect to examples of real music. Secondly, the space itself is drastically impoverished, and unable to support creativity that in any way could be considered comparable to the process of composition. As a minimum, the space must also contain concepts of musical structure, and concepts for describing relationships between musical structures.

Regarding the possibility of defining alternative regions in the space, it is interesting to note that even within this simple system, certain points of the space can be associated with particular genres of music. For example, if a techno 'four-to-the-floor' pattern is desired, a `kick-drum` pattern at point $\langle 0, 0, 4 \rangle$ might be valued. If one wanted a drum and bass syncopated `snare` rhythm, point $\langle 3, 5, 3 \rangle$ might suffice. Such spatially represented information might prove useful for agents in evaluating the suitability of potential rhythms in a given context, or to direct the search towards areas of potentially valued concepts.

Finally, it is not possible to reach a considerable area of the total space, as can be seen in Figure 1. Within a CSF, this presents an apt situation for potential transformational creativity. Since the search space is defined by a set of rules, a system capable of transformational creativity must be able to effect changes in the rules, bringing about changes in the space. Such changes could be brought about through aberrant discoveries, or by explicit 'exploratory creativity at the meta-level' [2, p. 454].

3.2 Timbre Space

The above system represents timbre on the symbolic level, but what does timbre look like on the conceptual and sub-conceptual levels?

An instrument's control may be broken down into a number of *parameters*. For example, the sound made by a guitar string depends on its length, tension and the force with which it is plucked. Each parameter provides a dimension of control, together forming a parameter space. We assert that the physical parameter space of a musical instrument has a strong bearing over the perceptual space that is invoked in the listener. In other words, the listener in part perceives a sound as movement in the parameter space that invoked it. This claim is supported by psychophysical measurement using statistical techniques such as Multi-Dimensional Scaling [8], where a direct mapping between parameter and perceptual space may be found [9, 10].

If given models of real musical instruments, creative agents could produce sound by making musical gestures informed by the same conceptual space perceived by humans—a space grounded in physical movement. In group musical improvisations, creative agents should also be able to represent the musical sounds of other performers in the conceptual space.

Neither the robotics required for a computational agent to play a real instrument nor the AI required to decode audio/visual stimuli into the movements of another musician are within our resources. Instead we turn to simulation. We employ waveguide synthesis [11] to simulate a drum-skin, adding a spring-and-mass model of a felt mallet from the work of Laird [12]. Sourcecode and video demonstrating its operation may be viewed in the on-line appendix [5].

The control parameters of our simulated drum and mallet form the domain $\mathcal{D}_{drum}$. The parameters consist of those controlling the drumskin (namely, tension and dampening), the mallet (stiffness and mass) and the manner in which the mallet is to hit the drum (downward velocity and path across the drumskin surface). Work is ongoing to employ Multi-Dimensional Scaling to explore the perceptual salience of these dimensions.

The symbols representing timbre in the rhythm space described in §3.1 could be replaced with points or regions in $\mathcal{D}_{drum}$. This would allow rhythms to be transposed across timbre space, and for similarity of rhythms to be compared not only by their structure but also the sounds used. Furthermore, labels could still be assigned to regions within $\mathcal{C}^c_{drum}$, preserving all functionality of a wholly symbolic system.

An agent may be granted access to the exact parameters used by others to create sounds from this simulated drum. As we are conflating action with perception, we could claim that the agent may then construct an accurate model of perception of the whole performance without having to analyse any audio data. However, while $\mathcal{D}_{drum}$ parameters may well have a strong bearing over perception, we feel there is at least one other domain at work – that of abstract timbre. By attending to a sound not as a drum stroke but in the abstract, the relationships between the sound events appear to shift. It seems as though there is competition between the perception of movement used to make a sound and the phenomenology of the sound itself, much like that reported in theories of speech perception [13], or common to electroacoustic music [14]. Clearly, proper testing is required to resolve these issues.

4 Conclusion

At its simplest, the conceptual level of representation introduces the notion of similarity to the CSF. From this we are able to view creative systems as navigating geometrical space, where distance, direction and shape all have meaning.

Our proposed conceptual domains for rhythm and timbre define spaces which agents may explore in order to create music. However there is much work to do. The spaces should be tested against human perception and adjusted accordingly, so that the agents may work in a perceptual space comparable to that of humans. The perennial question about how value is defined, both in terms of individual agents and agent communities must also be addressed. Creative transformations, perhaps employing cross-domain metaphor, must also be defined.

We are however greatly encouraged by the work presented here, which we hope goes some way towards providing a rich environment in which future creative agents may thrive.

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References

1. Gärdenfors, P.: Conceptual Spaces: The geometry of thought. MIT Press (2000)
2. Wiggins, G.A.: A preliminary framework for description, analysis and comparison of creative systems. Journal of Knowledge Based Systems (2006)
3. Wiggins, G.A.: Searching for computational creativity. New Generation Computing **24**(3) (2006) 209–222
4. Boden, M.: The Creative Mind. Abacus (1990)
5. Forth, J., McLean, A., Wiggins, G.: On-line appendix. http://doc.gold.ac.uk/isms/cspace/ (2008)
6. London, J.: Hearing in time: psychological aspects of music metre. Oxford University Press, Oxford, UK (2004)
7. Wiggins, G.A.: Models of musical similarity. Music Scienti **Discussion Forum 4a** (2007) 315–388
8. Shepard, R.: The analysis of proximities: Multidimensional scaling with an unknown distance function. i. Psychometrika **27**(2) (1962) 125–140
9. Grey, J.: Multidimensional perceptual scaling of musical timbres. Journal of the Acoustical Society of America **61** (1977) 1270–1277
10. Lakatos, S.: A common perceptual space for harmonic and percussive timbres. Perception & Psychoacoustics (62) (2000) 1426—1439
11. Van Duyne, S., Smith, J.O.: The 2-d digital waveguide mesh. In: Applications of Signal Processing to Audio and Acoustics, 1993. Final Program and Paper Summaries., 1993 IEEE Workshop on. (1993) 177–180
12. Laird, J.A.: The Physical Modelling of Drums using Digital Waveguides. PhD thesis, University of Bristol (2001)
13. Liberman, A.M., Mattingly, I.G.: The motor theory of speech perception revised. Cognition **21**(1) (1985) 1–36
14. Smalley, D.: The listening imagination: Listening in the electroacoustic era. Contemporary Music Review **13**(2) (1996) 77–107