

# TOWARDS THE BETTER PERCEPTION OF SONIC DATA MAPPINGS

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## ABSTRACT

There is a well-known perceptual problem that arises when abstract multivariate datasets of a certain size and complexity are parametrically mapped into sound for music composition or data sonification purposes. In listening to the results of such mappings, when a feature appears, it can be difficult to ascertain whether that feature is actually a feature of the dataset or a just a resultant of the interaction between psychoacoustically co-dependent parametric dimensions. A similar effect occurs in visualisation, such as when parallel lines can appear more or less curved on different backgrounds. Couched in psycho-philosophical terms, we may usefully ask whether this failure is related to classical phenomenology's inability to produce an eidetic science of essential invariant forms that involve no assertion of actual material existence, or to that there not yet having been found some generalisably acceptable limits from heuristically tested mappings. This paper briefly summarises the historical, philosophical and neurological nature of this problem and outlines an empirical approach to research investigating ways to improve such mappings by incorporating a model of embodied perception.

## 1. INTRODUCTION

Sonification is a relatively recent and multidisciplinary research area [1]. Parameter mapping sonification (PMS) is one such technique, the most widely used for representing multi-dimensional data as sound. PMSs can have both analogical and symbolic components. Analogic variations in the sound can result when mapping from a large data domain into a small perceptual range or when data is specifically mapped to acoustic modifiers such as frequency or amplitude modulators. PMSs are sometimes referred to as sonic scatter plots [2][3], nth-order parameter mappings [4], or multivariate data mapping, in which multiple variables are mapped to a single sound[5]. In this case data dimensions are mapped symbolically to sound parameters: either to physical (e.g. frequency, amplitude), psychophysical (e.g. pitch, loudness) or perceptually coherent complexes (e.g. timbre, rhythm). The term PMS frequently refers to multivariate data mappings in which multiple variables are mapped to individual sound objects. Scaletti describes one way of

implementing it by “mapping of each component of a multidimensional data point to a coefficient of a polynomial and then using that polynomial as the transfer function for a sinusoidal input” [4].

## 2. FOR SONICULATION OR MUSICAL EXPRESSION?

It is useful to distinguish data sonifications made for the purposes of facilitating communication or interpretation of relational information in the data, and data-driven music composition, ambient soundscapes and the like—the primary purpose of which is the expression of musical knowledge and broader cultural considerations, whatever they may be. The current use of the term “sonification” to include such cultural concerns is unfortunate because it blurs purposeful distinctions, yet today, the older expression “scientific sonification” seems unnecessarily restricted. So, for situations in which the distinction is considered important, the portmanteau term *soniculation* (from sonic + articulation) is used to mean the representation of data with sound with the principal and overriding imperative of making the structural characteristics of the data as clear and explicit to a listener as possible—even at the expense of other aesthetic considerations, if necessary[1]. In this regard, soniculation can be regarded as having a different *raison d'etre* than sonification when used as an algorithmic music composition technique, where achieving clarity for the structural characteristics of the data is not is not necessarily imperative.

Needing to maintain this distinction is not to suggest that there are not commonalities. In fact, as discussed later in this paper, the two activities can provide insights that are mutually useful. What is important is to maintain a critical awareness that because the purposes of the activities are different, so will their epistemological imperatives and consequences, such as in tool design and usability, for example.

## 3. “THE MAPPING PROBLEM”

There is a widely reported perceptual problem that arises when abstract multivariate datasets of a certain size and complexity are parametrically mapped into sound. Frysinger provides a useful overview of the history of the technique[6], and Flowers highlights some of its pitfalls

including that while “the claim that submitting the entire contents of ‘dense and complex’ datasets to sonification will lead to the ‘emergence’ of critical relationships continues to be made, I have yet to see it ‘work’” [3]. The main limitation of PMS is co-dependence, or lack of orthogonality (linear independence) in the psychophysical parameter space. Linear changes in one domain produce non-linear auditory effects, and the range and variation of such effects can differ considerably with different parameters and synthesis techniques. These perceptual parameter interactions can produce auditory artefacts that obscure data relations and confuse the listener. A similar effect occurs in visualisation, such as when parallel lines can appear more or less curved on different backgrounds. Kramer suggests that, although a truly balanced multivariate auditory display may not be possible in practice, given powerful enough tools, it may be possible to heuristically test mappings to within acceptable limits for any given application [5].

There is general agreement among sonification researchers that “the mapping problem,” is a significant impediment to an otherwise flexible and potentially powerful means of representing such information. Yet, despite the enunciation of general heuristics, the problem has essentially remained unsolved, suggesting the need for a paradigm shift if data sonification is to realise its potential as a general means of communicating information to a wide range of people. Elsewhere, I have outlined the historical and paradigmatic nature of this problem [7] [8]. Couched in psycho-philosophical terms, it can be described as an example of the failure of classical phenomenology to produce an eidetic science of essential invariant forms that involve no assertion of actual material existence.

I also showed how this problem is related to the problem faced by artificial intelligence researchers at MIT in the 1960s and '70s who tried to build a computational model of behaviour, know as (“strong”) Artificial intelligence (AI), based on representation and predicate calculus, and a misapplication of Shannon's information theory to *meaning*. Their atomistic approach has been all-but abandoned after its failure to represent the background knowledge and the specific forms of human “information processing” which are based on the human way of being in the world [9].

#### 4. NEURO-PSYCHO-PHYSICAL DIMENSIONS

Neither Gestalt psychology nor neurophysics has yet found generalisably acceptable limits from heuristically tested mappings, though recent findings in neuroscience (summarised in [10]) suggest a different paradigm of perception and behaviour is emerging that involves a reconceptioning of the role of body gesture in neuronal mirroring, including in aural perception. Next, I outline these findings as they provide a conceptual basis for the approach to be taken in the research proposed.

#### 4.1. Nonconsciousness in decision formation

Given the verifiable presence of nonconscious antecedents to an intention [11], it is unclear how formed our decisions are when we become aware and think of ourselves as “creating” them. The search for the neural correlates of consciousness has been aided by the ease of Functional Magnetic Resonance Imaging (fMRI) of cortical activity. However, it is suggested by Churchland and others [12][13] that the ready availability of such technologies has contributed to a cortical “chauvinism” that tends to concentrate on conscious perception at the neglect of the role they have in servicing behaviour. Specifically that, in service of keeping the body alive, the nervous systems of animals, as movers, function to service planning, deciding and executing these plans in movement.

Importantly, much of the brain's input is consequent upon the dynamical feedback loop between observed phenomena and an organism's own movements, exploratory and otherwise. This loop extracts vastly more information about the causal properties of the external world in a given time interval, leading to greater predictive prowess, i.e. skills regarding the causal structure of the world, than could a purely passive system.

Time is an essential component of causal knowledge, and predicting durations, interception intervals, velocities, and speeds of various body movements is critical to an animal's survival. Efference copy (being aware that a movement is one's own and not the world's) is also thought to be critical, as perhaps is the nonconscious “analysis” and memory of the movement of other movers, such as in predator-prey/pursue-evade relationships, for example. In contradistinction to the conventional wisdom that “the sensory pathways are purely sensory”, according to the Guillery and Sherman hypothesis, messages to the thalamus and cortex also carry information about ongoing instructions to the organism's motor structures [14]. Consequently, as a developing organism begins to interact with the world, sensory signals also “carry” gestural predictions: as an animal learns the consequences of a particular movement, it learns about what in the world will probably happen next, and hence what it might do after that.

#### 4.2. Learning and memory not just cerebral

Damasio's studies of efference copying of one's own thoughts and empathy with others provide even more evidence for this thesis that perception, learning and memory are not just cerebral processes but are embodied integrated into an organism as, what Polanyi called, tacit knowledge [15][12]. Kohler et al.'s finding, not only that that certain neurons in the ventral premotor area will fire when a monkey performs a single, highly specific action with its hand: pulling, pushing, tugging, grasping, picking up and putting a peanut in the mouth etc., but that that “mirror neurons” will also fire when the monkey in question observes another monkey (or even the

experimenter) performing the same action, offers some neurological basis for a theory of cultural inheritance, "mind reading" empathy, imitation learning, and even the evolution of language [16]. As Churchland observes,

*[B]y shifting perspective from "visuocentricity" to "motor-sensory-centricity," the singular importance of temporality becomes central and takes center stage in an hypothesis that "time management," for want of a better term, is the key to the complexity of tasks of thalamic nuclei, and very probably the key to a range of conscious phenomena as well [10].*

### 4.3. Acoustic mirror neurons

More recent studies have demonstrated that a mirror neuron system devoted to hand, mouth and foot actions is also present in humans. Buccino, Solodkin and Small review this literature and that of the experimental evidence on the role of the mirror neuron system in action understanding, imitation learning of novel complex actions, and internal rehearsal (motor imagery) of actions [17]. Important for this proposal, is the finding that actions may also be recognised from their typical sound, when presented acoustically. Besides visual properties, it was found that about 15% of mirror neurons, called audio-visual mirror neurons, also respond to the specific sound of actions performed by other individuals even if only heard [18].

It has been argued that these neurons code the action content, which may be triggered either visually or acoustically. Phillips-Silver and Trainor demonstrated an early cross-modal interaction between body movement and auditory encoding of musical rhythm in infants [19]. They found that it is primarily the way adults move their bodies to music, not visual observation, that critically influences their perception of a rhythmic structure. Their results suggest that while the mere visual observation of a conspecific's goal-directed movement (e.g., reaching for an object or hand-to-mouth action) is sufficient to elicit a neuronal representation of the action, this does not transfer to the domain of metrical disambiguation [20]. So it appears that either this type of rhythmical body movement is not an example of the kind of object-directed action that activates the mirror neuron system or the information provided by the mirror neurons is not strong enough to influence the later-recalled auditory metrical representation of a rhythmic pattern.

### 4.4. Action-based sonic sensibility

In an experimental study of gestures, subjects of various ages were able, with a high degree of accuracy, on only hearing different individual human's walking and running on various kinds of surfaces, to determine their sex [21]. A consequential inference is that differences in ambulatory action, presumably resulting from relatively small differences in skeletal anatomy, is tacitly 'available' to listeners. Also consequent to these findings is the need for better models of multimodal sensory input,

particularly with respect to the integrative functions of vestibulation and proprioception, which some empirical evidence suggests are available to listeners though aural means alone [22][21].

A new movement-encompassing action-based approach to the relationship between sound and sensibility began in the 1980s [23]. Methodologies include the use of abductive as well as inductive inference are contributing to new perspectives on how to approach the relationship between sensibilities [22][24]. In some ways this can be seen as a return to the Aristotelian integration of sound and sensibility through mimesis and related to the Kantian problems of openness and endness in the containment of beauty in formal structures and the empathic relationship within them through movement and action [25].

As their ability to understand musical structures shows, humans have the capacity to create, transmit, receive, transform and most importantly for the research outlined below, recall certain types of immanent objects using sound. The idea that musical involvement is based on the embodiment of movement and the bodily sensing of music, has a long history, of which the traditional connection between dance and music is but a gross example. Truslit studied the body movements of musical performers and suggested they were articulations of inner movements in the music itself [26]. Central in Truslit's approach to musical movement are the notions of dynamics (intensity) and agogics (duration). If the music has the dynamo-agogic development corresponding to a natural movement, it will evoke the impression of this movement. He makes a distinction between rhythmic movement and the inner movement of the music. In contrast to rhythmic movement, which is related to individual parts of the body, the inner movement forms the melody via the vestibular labyrinth of the inner ear and is related to the human body as a whole. Both Nettheim [27] and Clynes [28] also make a connection between music and gravitational movement, based on the idea of a dynamic rhythmic flow beyond the musical surface.

## 5. THE BODY IN COMPUTER MUSIC

The relationship between the rise of AI and computer music research is more than just anecdotal. Computer music developed in the second half of the twentieth century largely in its shadow, especially in the design of computer music (composition) software such as Music V [29] and its derivatives, many of which are still actively in use.

While there have been significant advances, these have been principally in the use of model-based approaches such as physical modelling for timbres synthesis and perhaps connectionist approaches more generally [30]. There is still a deep conceptual disconnection between the immediate appeal of much music made with simple electronic instruments and the commonly expressed affect that, despite the enormous investment by researchers in developing sophisticated

computer sound-synthesis models in order to make them more 'life-like', much computer music still appears too abstracted and 'other-worldly' to the general public.

There are cultural and 'language' dimensions to this issue that have protected the problem from critical exposure to its causal analysis: a weakness created by a strong historical alliance between rule-based representational algorithmics and AI research [31].

This is not to suggest that no interesting music has been composed using AI-aligned techniques—music does not have to be 'natural' or even consistent to be interesting or culturally impactful, as the many of the results of using equal temperament attest— but an attempt to temper and modernise the connection between sound synthesis software and music composition in ways that take account of listeners as embodied beings. Such an approach is in confluence with the contribution that (post-)phenomenology is making to contemporary AI research [32][33].

### 5.1. Empirical musicology, HCI and soniculation

Merleau-Ponty divides embodiment into three modes: innate structures, basic general skills, and cultural skills [34]: the way our bodies are built, the skills we learn through our bodies, and learned ('cultural') interactions that are not directly tied to the way our bodies are built. In a growing realisation of the vital importance of accounting for the embodied nature of our interactions with the people, objects and processes, recent approaches to human-computer interaction (HCI) are attempting to make their interactions analogous to those of human-to-human and human-to-the-natural-world.

In many ways, the tradition of emphasising intentional cognition over embodied approaches has never really been totally applicable to musical sensibility. In fact, all music except those esoteric forms that seek to represent abstract algorithmic processes or in which sound is *bricolered*, encode embodied gestures in some form or another. Recent studies in empirical musicology, including the mensural study of instrumental performer's gestures, and the neurophysical analysis of instrumental performance in general, is becoming recognised as at least as important for understanding musical ideas as notated structural abstractions (scores) [35][36]. While the empirical studies of performer gestures has some relevance to the soniculation of multivariate datasets, in being more analytical than generative, it is largely deficient for the purpose.

At the same time, there is growing interest in human/machine interfaces, such as those for motion detection, that enable musicians to produce computer-generated sounds under nuanced gestural control [37][38][39]. Currently, real-time performer-machine interaction is more concerned with producing convincing musical results, as traditionally evaluated, than in an empirical evaluation of the gestures themselves or their perceptibility.

However, by leveraging the analytical knowledge made available by them to the construction of

generative models of information-encoded sound that is perceivable more reliably and more tacitly, that is, with a lower cognitive load, than is currently available, both empirical musicology and musical performance HCI *are* laying a foundation for their results to be applied to generating more perceptible sonicated information structures from multivariate datasets, as well as in developing new lexical tools for musical expression.

## 6. TOWARDS A GESTURE-ENCODED SOUND MODEL

A programme of research has begun that seeks to empirically demonstrate whether or not the perceptual access to the structural and informational content of multivariate datasets through sonification based on a model that incorporates the aural transduction of known temporal embodiment affordances such as human gestures, is superior to one based on elementally composed aural *objects* that are *observed* and rationally conceptualised. Philosophically, this is an approach based on an embodied phenomenology of perception first enunciated by Merleau-Ponty [34] and extended by Todes [40].

An extensive search of the literature has not revealed any other approach that addresses the issue of how to use the innate structures of the human body, expressed through gesture and transmitted aurally, to improve the "eyes-free, hands-free" tacit grasping of ideas and information contained in the increasingly large and complex datasets that are becoming a part of our daily lives—from climate and the weather to fluctuations in the financial markets and traffic flow. The research we are currently undertaking is to develop a model of (human) physical and sonic gesture correlates. The task is essentially to apply captured biomechanical data with sound-derived components (timing, spectral morphology etc) and known psychophysical principles as inputs to an iteratively trained Dynamic Bayesian Network (DBN).

This Gesture-Encoded Sound Model will then be used to produce an active filter for transducing multivariate datasets to sound synthesis and control parameters. The approach renders a datastream to sound not only using observable quantities (inverse transforms of known psychoacoustic principles)[41], but latent variables of a DBN trained with gestures of the physical body movements of performing musicians and hypotheses concerning other observable quantities of their coincident acoustic spectra. The research on the model will be integrated as an extension to *SoniPy*, the author's open-source software framework that integrates various existing independent component modules, such as those for data acquisition, storage and analysis, cognitive and perceptual mappings as well as sound synthesis and control, by encapsulating them, or control of them, as Python modules [42].

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