PARAMETER MAPPING SONIC ARTICULATION AND THE PERCEIVING BODY

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ABSTRACT

In data sonification research, there is a well-known perceptual problem that arises when abstract multivariate datasets of a certain size and complexity are parametrically mapped into sound. In listening to such sonifications, when a feature appears, it is sometimes difficult to ascertain whether that feature is actually a feature of the dataset or just a resultant of the psychoacoustic interaction between 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 can 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 there not yet having been found some generalisably acceptable limits from heuristically tested mappings. This paper discusses the nature of this problem and introduces a sonification research project based on embodied, non-representational phenomenal models of perception.

1. PARAMETRIC MAPPING SONIFICATION (PMS)

The use of discrete sounds for auditory alerts and alarms presents sound designers primarily with differentiation problems: both between the sounds themselves and between the sounds and the background environment in which they function. Though related in subtle ways, these discrete auditory displays do not address another problem: how to acoustically represent data *relations* for interpretation by listeners, for the purpose of increasing their knowledge of the source from which the data was acquired. That task can be recast as one of how to use sound to create mental 'objects' for active contemplation, as distinct from how to correctly elicit a timely response to already well-differentiated auditory stimuli.

The term 'data sonification' is usually reserved for a collection of techniques for exploring datasets that have an equally–spaced metric in at least one dimension and in which there are sufficient data points to afford continuous aural interpolation between them[1]. Such dataset representations are most commonly used to learn more about the systems that produced them. Applications range from monitoring the real-time operation of machines, capital–market trading, geographic and demographic features, weather and the environment and so on; as tools to assist in the discovery of features and new regularities, and to assisting those with visual impairment to gain access to large quantities of information normally presented graphically.

Parameter mapping is the most widely used sonification technique for representing multi-dimensional data as sound. Parameter mapping sonifications (PMSs) are sometimes referred to as sonic scatter plots [2][3] or n^{th}–order parameter mappings [4]. Typically, data dimensions are mapped to sound parameters: either to physical (frequency, amplitude), psychophysical (pitch, loudness) or perceptually coherent complexes (timbre, rhythm). 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. PMS is sometimes referred to as *multivariate data mapping,* in which multiple variables are mapped to a single sound. 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]. Within an overall analogic mapping, symbolic representations such as auditory beacons [5] can be used to highlight features such as new maxima and minima, or absolute reference points in a sonification such as ticks to indicate the regular passing of time.

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 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) has been introduced 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].

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, for example, in tool design and useability.

3. "THE MAPPING PROBLEM"

A contemporary overview of the current range of sonification and other auditory display techniques is available[1]. The technique discussed here, parametric mapping sonification (PMS) has a number of positive aspects, which Scaletti first outlined in some detail [4]. Many data dimensions can be listened to simultaneously. It is very flexible and the mappings can be easily changed, allowing different aural perspectives of the same data. In addition, acoustic production can be assigned to sophisticated tools originally developed for computer music synthesis. These are readily available and permit many quite sophisticated parameter mappings to be synthesised in real-time.

Frysinger provides a useful overview of the history of the technique[6], and Flowers highlights some of its pitfalls and possible future directions. An experienced multivariate data sonifier, he observed 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 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 artifacts that obscure data relations and confuse the listener. 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].

In many discussions of data sonification, the distinction between *data* and *information* is often lost. In fact, the expression *data sonification* itself promotes an elision and in doing so, implicitly supports the idea that information can automatically "pop-out" of a sonification once an optimal parameter-mapping of the dataset is found. The purpose of this paper is to argue why this is unlikely (except perhaps for those who have had advanced aural training acquired over many years), and to argue that it is necessary to search for general solutions outside of explicitly representational paradigms.

4. THE AUDITORY OBJECT

The historical record of the study of perception clearly reveals the overwhelming dominance of arguments based on the visual appearance of spatial objects; sounds not being considered as objects in themselves but as secondary properties of spatial objects and not essential to their ontology [7].

In tracing the roots of this "visualism" in pre-Socratic Greek thought, Ihde concludes, citing Aristotle, that it is as old as our own cultural heritage: "Above all we value sight … because sight is the principle source of knowledge and reveals many differences between one object and another."[8]. So the dawn of modern science was essentially a silent one and yet-to-be-captured sound still quite mysterious. One of Descarte's undervalued attributes was his honesty [9]:

> *As to other things such as light, colours, sounds, scents, tastes, heat, cold and the other tactile qualities, they are thought by me with so much obscurity and confusion that I do not even know if they are true or false, i.e. whether the ideas which I form of these qualities are actually the ideas of real objects or not [or whether they only represent chimeras which cannot exist in fact].*

The idea that an aural event could be objectified and studied in its own right, that is independent of the means of its production, evolved slowly and in parallel with the development of the concept of a musical work as reproducible from notation [10] and eventually with the use of various sound recording devices invented during the nineteenth and twentieth centuries.

A distinction between the physical sounds (noumena) and aural events (phenomena) is not just a philosophical one. It is important that these two types of objects are not conflated as there is an enticement to do when the (software) tools designed to produce soundwaves are also used to produce abstract aural phenomena, that is, immanent objects. One difficulty that arises when tools from one task domain are appropriated to another is the implicit transfer of the epistemological assumptions of the former to the latter; an idea expressed in the saying "to a person with a hammer, everything looks like a nail". In the current context, this translates to the assumption that tools used to produce sounds for computer music are appropriate, or at least adequate, for producing data sonifications. In fact, the particular situation is even more convoluted as the tools designed to make computer *music* have themselves embedded an epistemology of *music* which privileges the production of the *sounds* of music over its other aspects, such as gesture and temporal evolution. This "timbre object fetish" in computer music can be understood as having an historical basis in the early relationship between computer music and artificial intelligence research, both of which have continued the doctrine of isolating *res cogitans* from *res extensa* and prejudiced the former over the latter (*cogito ergo sum* – "I think therefore I am").

5. UNDERSTANDING THE AURAL PHENOMENA

As perceptual phenomena, it is appropriate to make a distinction between those sonifications that result from the excitation of physical objects (or synthetic simulations that closely approximate them, such as homomorphic modulation and those based on physical modeling principles), and those, such as a parametrically mapped datasets, that are artifacts of perceptual processes in which elementally composed soundpoints are assembled in such as way that the psychophysical continuity of at least some of the parametric dimensions conflates the perception of those soundpoints into a single immanent object or perceptually coherent auditory scene.

The reason such a distinction is important is that physical objects obey physical laws that human beings have evolved to recognize the effect of with negligible attentional effort, whereas sound structures synthesised from numerical datasets may not. In the physical-modeling case, data is used to excite a "self-contained" resonator (an integrated unity obeying physical laws)[1], or perhaps less convincingly, the data itself is used to construct a physical model that is "resonated" by a listener interacting with it [11][1]. In the case of objects synthesised from numerical datasets, the elementally composed soundpoints are 'presented' to listeners in ways that it is hoped afford their perception of the form of the dataset. Perception is thus understood as human behaviour and soniculated PMSs as sound constructions 'imprinted' in multi-dimensional psychophysical space to elicit a perceptual behaviour which affords the cognition of the form of that structure as an (auditory) object in the listener.

While, in his ground-breaking overview, Bregman described the basic elements and dimensions of analytic and synthetic listening in terms of auditory stream integration and segmentation [12], the current PMS model doesn't work very well and there is yet to be written a generalized exposition appropriate for many sonification tasks: how to synthesise perceptual cohesion while maintaining aurally differentiable soundpoints. It remains a task of soniculation research to develop robust models of listener's perceptual behaviour that can be reliably reverse-engineered to produce affordances that solicit listener's to behave in ways that assist them to get enough 'grip' on these sound structures for them to be perceived as cohesive auditory objects.

Exactly how these perceptual mechanisms work is open to speculation and investigation. In-keeping with the Cartesian tradition, there have been two kinds of investigation, which we label 'mental' and 'empirical'. We review these two approaches before offering a critical discussion that leads to a proposal for a different approach.

5.1. The mentalists

According to Kant's understanding, what exactly is meant by *information* is embedded in relationships between the sensation, perception and apperception of phenomena; what he called *appearances (Erscheinungen):* things as they are for humans, as opposed to things as they are 'in–or–of–themselves' (*Ding an sich)* otherwise known as *noumena*. From this perspective, information can be simply characterized as phenomena, or thoughts about phenomena in the mind of some person [13].

Following Kant and the Idealists, Brentano and his students Meinong and Husserl investigated the perceptual world as a rational or mental construction of a perceiving subject. Their phenomenological method (a contemplative and descriptive psychology as distinct from the newly developing natural or empirical psychology) entailed "bracketing off" (with an attitude Husserl called *époché*) phenomena ('things-as-we-know-them') from the physical world (Kant's 'things–as–they–really–are'), in and attempt to discover the underlying structures and forms of the objects produced by intentional mental processes; firstly in the mind of the perceiver and secondly as sharable with others—a characteristic Husserl called *intersubjectivity.* Brentano expressed it like this [14]:

> *Every mental phenomenon is characterized by what the Scholastics of the Middle Ages called the intentional (or mental) inexistence of an object, and what we might call, though not wholly unambiguously, reference to a content, direction toward an object (which is not to be understood here as meaning a thing), or immanent objectivity.*

Brentano's goal was to outline the criteria for distinguishing mental and physical phenomena. He used the terms *mental or intentional inexistence* to refer to what today is sometimes understood as a characteristic of consciousness: the mind's capacity to *refe*r or be *directed* to objects that exist solely in the mind. Meinong's concern was with the intentional *relation* between the mental act and an object. He maintained that such a relation existed even when the object external to the mental act towards which it is directed doesn't exist, such as Pinocchio, Orpheus, Unicorns and the Fountain of Youth. Earlier, Hume had considered the concept of non-existent objects contradictory, Kant and Frege considered it logically ill-formed though later, Russell adopted the idea [15].

In cases of temporally extended objects ('events') like melodies, Brentano argued such objects towards which we are directed do not immediately vanish from consciousness once the mental act is over. They rather remain present in altered form, modified from *present* to *past*. Every mental phenomenon triggers an 'original association' (*proteraesthesis)*, a kind of memory which is not a full-fledged act of remembering, but rather a part of the act that keeps lively what was experienced a moment ago. When I listen to a melody, for example, I first hear the first tone. In the next moment I hear the second tone, but am still directed towards the first one, which is modified, though, as past. When I hear the third tone, the second tone is modified as past and the first is pushed back even further into it.

Though Peirce thought that there can be no perceptual objects without a unifying factor that distinguishes them from the 'play of impressions', Husserl's aim was to develop an *eidetic* science; one of essential, invariant phenomenal forms that involves no assertion of actual material existence. However, he struggled to keep them conceptually separate from Plato's Ideas.

In the 1960s, following the lead of Descarte, Kant and Frege, and a misapplication of Shannon's information theory to *meaning* [16], Minsky lead a team at Massachusetts Institute of Technology aimed at modeling intelligent behaviour artificially, using symbolic representation and the predicate calculus. Their atomistic approach was abandoned after its failure to represent the background knowledge and specific forms of human "information processing" which are based on the human way of being in the world. This way of "being-in" turned out to be syntactically and thus computationally unrepresentable using currently conceivable techniques [17] [18].

5.2. The empiricists

In ecological terms, the objects and the environment in which they reside, afford listener exploration. For Gibson[19], following Gestaltists such as Wertheimer, Koffka, Kohler and Mach, these affordances were thought to be *in* the physical objects and our observation of them consists of us (somehow) forming a representation of them in our heads; the Gestaltist's task being to empirically search for the means by which the brain more–or–less unconsciously perceives the forms of objects received from sense data.

The Gestaltists discovered perceptual invariants such as the figure–ground phenomena, which they considered as arising directly from the physical nature of sensations derived from the noumenal world. However, they were not able to extend the idea past sensations. It is a characteristic of such phenomenal forms that their properties can remain unchanged when the objective stimuli upon which they rest undergo certain modifications. This phenomenon of identity is part of a much more general issue in topology and mathematical group theory; of invariances with respect to transformations of the primitive elements out of which a form is constructed. The mathematical concept of transformability corresponds to the concept of transposability in perception. So by accepting "form" as a primitive concept, Gestalt psychology made an attempt to free psychological theory from contingency on the mere mosaic of perceptions.

Not all group-theoretic transformations of perceptual objects are equally cognized, nor are the same transformations as easily perceivable in different sense modalities. For example, symmetry group transformations of pitch and temporal structures, such as transposition, inversion and retrogradation, occur frequently in music though they seem not to be all equally evident to the casual listener: under non-extreme pitch transposition and tempo acceleration a melodic structure remains strongly invariant; pitch contour inversion and rhythmic retrogradation are common occurrences in some musics but are not as strongly invariant, while rhythmic inversion seems not to be perceptually invariant or even generally defined.

6. SUB-CORTICAL NEURAL ACTIVITY

Whilst a considerable amount is known about the structure and functions of individual neurons, the fundamentals of how macro effects emerge from populations of neurons are still largely unknown, despite considerable effort over the last decades. As the field develops, there is a growing realisation that the phenomena associated with "consciousness", "nonconsciousness" and "cognition" are too diverse to continue to be meaningfully subsumed under the same ill-defined terms [20]. For example, given the verifiable presence of nonconscious antecedents to an intention [21], it is unclear how formed our decisions are when we become aware and think of ourselves as mentally ''creating'' them.

6.1. Neural correlates of consciousness

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 [22][23] 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, that is, 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 [24]. 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.

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 embodily integrated into an organism as, what Polanyi called, tacit knowledge [25][22].

6.2. Mirror neurons

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 [26]. As Churchland observes, by shifting perspective from "visuocentricity" to "motor–sensory-centricity," the singular importance of temporality 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 also to a range of conscious phenomena [20].

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 [27]. The finding that actions may also be recognised from their typical sound, when presented acoustically has important implications for embodied soniculation research. 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 [26]. 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 [28]. 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 [29]. 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.

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 [30]. 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 multi-modal 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 [31][30].

7. CRITICAL DISCUSSION

While knowledge of the structure and functions of individual and clusters of neurons is increasing, there are billions of them, each with tens-of-thousands of connections so there is no certainty, even when the overall functioning of the neural system is significantly better understood that it currently is, that such an understanding will be able to adequately account for the ability to synthesise perceptual objects. In fact, if the *rate* at which pulses are transmitted turns out to be the minimum unit in an account of the relevant activity of the nervous system [32] and the diameter of an axon, which might be a function of the recency of a signal passing down it, plays a crucial role in processing information by acting as a filter [33], there is no reason to believe that information processing at neurological-level can ever be formally described [17].

The mentalist approach has failed to find any means by which mental representations can be reliably accumulated for conscious reflection, at least not without a good deal of training and effort. This somewhat explains some of the difficulties reported in PMS research that the vast majority of ordinary listeners, for whom a low conceptual loading is necessary for continued engagement, are precluded from making 'sense' of them just as the attempt to use computers to develop an 'artificial intelligence' based on computational theories of mind that rely on a classical reductionist approaches such as "mind is to software as brain is to hardware" failed to be able to understand even the simplest stories because of the unrepresentability of the background knowledge and the specific forms of human "information processing" which are based on their way of being in the world. This suggests that, when compared with the ease with which everyday sounds are identified; the ease with which a myriad of melodies are learned, remembered and identified, that the mentalist approach is inadequate at best. More likely, that it is just wrong.

The relatively recent availability of tools to abstract sound from its origin in the physical action of objects, and the development, alongside that of "good-old-fashioned-AI (GOFAI)[34] of seminal software for computer music [35], has blurred the functional distinction between sound and music, much as often occurs between data and information, and information and meaning. Sound recording enabled Schaeffer, building on the philosophical foundation of Husserlian (that is mentalist, *épоché*) phenomenology, to propose a musical analysis based on *reduced listening*, that is listening to sounds for their own sake, as sound objects, by removing their real or supposed sources and meanings [36]. It is of particular interest in the light of the previous discussion of the role of time and causality in perception, that while Schaeffer does discuss tempo and temporality, he makes almost no reference to pulse and rhythm.

8. THE PERCEIVING BODY

Husserl's pupil Heidegger was critical of the subject/object split that pervades the Western tradition and that is in evidence in the root structure of Husserl and Brentano's concept of intentionality, that is, that all consciousness is consciousness of something, and (the idealist notion that) there are no objects without some consciousness beholding or being involved with them. Heidegger encompassed terms such as "subject", "object", "consciousness" and "world" into the concept of a mode of "being-in-the-world" as distinct from an essentially Positivist "knowing" of objects in the universe that is required for navigating the environment–measurement, size, weight, shape, cause & effect etc. His Being-in-the-world is characterized as "ready-to-hand"[37]:

> *. . the kind of dealing which is closest to us, not a bare perceptual cognition, but rather that kind of concern which manipulates things and puts them to use; and this has its own kind of 'knowledge.'*

In other words, participatory, first-hand experience: familiarity, tacit know-how, skill, expertise, affordance, adaptability etc. Heidegger argues that our scientific theorizing of the world is secondary and derivative and he exposes an ontology that is far broader than the dualistic Cartesian framework. He stresses the primacy of the readiness-to-hand, with its own kind of knowing or relating to the world in terms of what matters to us. It follows, from Heidegger's perspective, that human action is embodied, that human knowing is enactive, and participatory.

The Hungarian scientist and philosopher, Polanyi proposes a type of participative realism in which personal knowledge plays a vital and inescapable role in all scientific research, indeed, in all human knowing [38]:

> *Let us therefore do something quite radical … let us incorporate into our conception of scientific knowledge the part which we ourselves necessarily contribute in shaping such knowledge.*

By stressing the tacit nature of participatory knowing, Polanyi claimed that "we know more than we can tell". In this way he emphasised knowledge that is implicit to tasks, situations and attitudes. He used the term *tacit knowledge* to refer to those things we can do without being able to explain how, that is, in the absence of explicit rules or calculative procedures. The "indwelling" nature of tacit knowledge is important in the development of the skill of reflexivity, such as needed in the sifting through and interpretation of qualitative data.

Heavily influenced by both Husserl and Heidegger, Merleau-Ponty produced a much more developed understanding of the body and its role in non-conceptual perception [39][40]. As the only major phenomenologist of the first half of the twentieth century to engage extensively with the sciences, he was able to systematically demonstrate the inability of the mentalist and empiricist explanations to adequately account for observed phenomena. In doing so, he produced a theory of perception in which the body and the world are entwined; in which perception occurs through the "intentional tissue" of the "body schema" (*schéma corporel*); much as epigenetic alterations occur in a phenotype by the osmotic transduction of molecules through semipermeable membranes.

Todes builds on Merleau-Ponty's work by beginning to work out a detailed phenomenological account of how our embodied, nonconceptual perceptual and coping skills open a world to us. He then works out twelve perceptual categories that correspond to Kant's conceptual categories, and suggests how the nonconceptual coping categories can be transformed into conceptual ones [41].

9. SO WHERE IS THE BODY IN SONICULATION?

The reduction of music to noises–in–the–head is supported by the wider cultural practice of using visual terminology to describe aural phenomena. Such a privileging of the visual over the aural too easily promotes the unwarranted prejudicial masking of one dimension over another. The implication of the privileging of visual experience, especially when it is conceived principally to be by stationary beings of stationary *ob*jects that are *ob*served[1] and only then perhaps with movement, is to, albeit subtly, privilege the spatial over the temporal; sound 'objects' over gestural dynamics. Applied to soniculation, such an epistemology weakens the strongest ontological scaffolding that supports temporal perception as primary means by which information can be transduced through sound to the perceiving body.

A new movement-encompassing action-based approach to the relationship between sound and sensibility began in the 1980s [42]. Methodologies include the use of abductive as well as inductive inference, and are contributing to new perspectives on how to approach the relationship between sensibilities [31] [43]. 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 [13].

[1] From L. *ob*-"over"+ *servare* "to watch, keep safe" and *ob*-"against"+ *jacere* "to throw," as in a jet [49].

It seems reasonable to suggest that continuing to flip-flop between the mental-empirical antinomy, in anticipation that one or the other will eventually provide an applicable model for PMS, may be a forlorn hope. There seems little point in speculating whether or not listening will ever regain the relative importance to humans it enjoyed prior to the European En*light*enment, but there are signs of a growing recognition that the resolution of the mind/body dilemma will not be solved by dispensing with the body.

In many ways, the tradition of emphasising disembodied cognition over alternative approaches has never really been totally applicable to musical sensibility. Clearly humans have the capacity to create, transmit, receive, transform and most importantly recall certain types of immanent objects using sound: music can afford them all! 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 [44]. 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 [45] and Clynes [46] also make a connection between music and gravitational movement, based on the idea of a dynamic rhythmic flow beyond the musical surface.

Empirical musicology, including the mensural study of performance practices, together with neurophysical analysis of 'embodied' instrumental performance, is becoming recognised as at least as important for understanding musical ideas as notated structural abstractions [47][48]. There is growing interest in human/machine interfaces that enable musicians to produce computer-generated sounds under nuanced gestural control [49][50][51].

Both empirical musicology and gesturally-controlled computer-music performance are of relevance to this investigation. However the former, is deficient in being largely analytical and the latter, in being little interested in empirical evaluation. Between the two, it may be possible for future soniculation researchers to recognise the limitations of the current PMS paradigm, to accept that musical information can be intelligible, that is capable of being *soundly understood*[2], through temporally-encoded "second-order" structures and undertake research to ascertain the viability of a variety of embodiment models under controlled conditions. The beginning described in the next section is but one example of an empirically approach which may or may not prove fruitful.

[2] O.E. *understandan* "comprehend, grasp the idea of," probably lit. "stand in the midst of," from under + standan "to stand". O.E. under, from **nter*- "between, among" (cf. Skt. *antar* "among, between," L. *inter* "between, among," Gk. *entera* "intestines"[52].

10. 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 *ob*jects that are *ob*served and rationally conceptualised. Philosophically, the is an approach based on an embodied phenomenology of perception first enunciated by Merleau-Ponty [39] and extended by Todes [41].

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), 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* [53].

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