SONIFICATION: A PREHISTORY

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ABSTRACT

The idea that sound can convey information predates the modern era, and certainly the computational present. Data sonification can be broadly described as the creation, study and use of the non-speech aural representation of information to convey information. As a field of contemporary enquiry and practice, data sonification is young, interdisciplinary and evolving; existing in parallel to the field of data visualization. Drawing on older practices such as auditing, and the use of information messaging in music, this paper provides an historical understanding of how sound and its representational deployment in communicating information has changed. In doing so, it aims to encourage a critical awareness of some of the socio-cultural as well as technical assumptions often adopted in sonifying data, especially those that have been developed in the context of Western music of the last half-century or so.

1. INTRODUCTION

We are at a time in the evolution of humans and their tools when the power of digital information processing and algorithmic decision-making is demonstrating an ability to radically change our lives: From genetic finger-printing, gene-splicing and pharmacology, to driverless vehicles, patterns in our consumption and how we amuse ourselves. Even now, so early in this new Dataist era, organizations with networked computational intelligence already have access to more data about ourselves that we ourselves have access to, and are beginning to demonstrate a power to make better decisions for us than we make for ourselves. What, then, one might reasonably ask, is the use of exploring such ancient, intensely-human-centered approaches to information-gathering and decision-making as listening? How old-fashioned; how quaint! This is an increasingly pertinent question and the answers are not necessarily obvious as they lie at the heart of the difference between a conception of life merely in terms of information flow and data storage as might be imagined by the Cognitivists [20], and one in which mind, body and (now technologically enhanced) consciousness play a fundamental role in active perception, knowledge acquisition, meaning-creation and decision-making.

In a contemporary media-saturated environment, sound plays a wider variety of different social and communicative roles today than it ever did in the past. Although computer-generated data sonification is a relatively recent formalized practice, cultural antecedents can be identified in all periods of history. In the spirit of the adage "know from whence you came," anecdotes and general trends are instructive because they provide insights into what people thought sound was and how it could be used to communicate.

The idea that sound can convey non-speech information predates the modern era, and certainly the computational present. By considering some ways in which sound has been used in the past to convey specific information, this paper attempts to provide a focused historical understanding of ideas about sound and how its deployment in communicating information has changed in the modern era. In doing so, it is hoped that this will assist us to critically examine the socio-cultural assumptions we have adopted, particularly with regard to the current practice of data sonification. Whilst acknowledging their Eurocentricity, there is no suggestion that the ideas discussed here do not have wider applicability.

In the process of uncovering the accuracy of our assumptions about human perception, it is easy to be seduced into a type of sense war, in which hearing and listening are pitted against vision and seeing. Each have their place and so to be encumbered with such a burden is not useful, particularly when a focus on one sense assumes or leads to the decline of another. Such casting can take many forms. What is to be gained by Marshal McLuhan's myopia, for example?

> *The ear is hypersensitive. The eye is cool and detached. The ear turns man over to universal panic while the eye, extended by literacy and mechanical time, leaves some gaps and some islands free from the unremitting acoustic pressure and reverberation* [16, p168].

Thankfully, the discussion has moved on, at least in some circles. This is not to deny that there are sensory differences; in fact it can be instructive to identify them. For example, it is hearing, not vision, that affords omnidirectional coherent perceptual experiences. For all moving creatures, including our ancestors, both ancient and modern, in situations where sight is obscured, spatial auditory clarity plays a vital survival role in determining both from where the predator is approaching and to where the prey has escaped. On the other hand, we can suppose that, to a creature sleeping in a cave, being alerted early by the amplifying echoic resonance of the space that something of a certain mass was entering, was more important than details of its exact position.

2. HISTORICAL USES OF SOUND TO CONVEY INFORMATION

There are many reasons why, in certain circumstances, sound might be the preferred representation and communication medium for information, including the known superiority of the hearing sense to discriminate particular kinds of structures. For example, it is easy for most of us to personally verify that a purely visual side-by-side comparison of two sets of written records requires high levels of concentration and that doing so is very prone to error, especially over extended periods of time. One the other hand, listening to vocalizations of such representations is much easier. The presence of such auditing can be inferred from records of Mesopotamian civilizations going back as early as 3500 BCE. To ensure that the Pharaoh was not being cheated, auditors compared the "soundness" of strictly independently-scribed accounts of commodities such as grains moving in and out, or remaining, in warehouses [3]. When granary masters, otherwise strictly isolated from each other, assembled before the Pharaoh and alternated in their intoning of such records, differences in their accounting records could be easily identified aurally. A faster and more secure method that eliminates any "copy-cat" syndrome in such alternation, is to have the scribes read the records simultaneously–a type of modulation differencing technique. Although we have no hard evidence that these techniques were practiced, such a suggestion does not seem unreasonable, and would represent possibly the earliest form of data sonification.

Sound has also played an important role in both theoretical and empirical inquiry for millennia. At least as far back as Pythagoras (born ~569 BCE), the concept of The Harmony of the Spheres played a unifying role in the development of the arts and sciences, and incorporates the metaphysical principle that mathematical relationships express qualities or "tones" of energy ratios. The application of number relations (i.e. ratios) and sound have been integral to the conceptualization and realization of Western music over all periods in radically different ways: From the development of richly fecund investigations in tuning and temperament to multiple voice polyphony and to highly chromatic polytonalities; serialized additive rhythms to stochastic mappings controlled by Poisson's distribution, for example.

3. THE EAR AS THE ORGAN OF THE CHURCH

In pre-medieval Europe, the Roman Catholic Church eventually filled the political and spiritual vacuum caused by the collapse of the Roman Empire around 500 CE and went to extraordinary lengths to establish supreme papal power, culminating in the construction of massive reverberant cathedrals, which replaced the echoic caves of the past to become temples in which the resonant voice of an omnipresent God, through the pope and his priests and their choirs, was delivered to a largely passive, observing audience; silenced by the unintelligible Latin and the presence of the holy sacrament, for the safety of their immortal souls. Even though the church almost universally forbade the use of all instruments of "profane" music in worship, sometime during the tenth century large *Blockwerk* organs began to be permanently installed in churches and cathedrals. By producing the lowest-pitched and most powerful musical sounds of the period, these organs resonated the buildings in which they were installed, and impressed on congregations a power found only in the church. In addition, these modern caves were engineered to produce an awe-inspiring, comforting, inclusive "community" feeling through spatial aural reverberant incoherence, and by which potentially questioning or dissenting individuals were subsumed into the anonymity of the Mass.

When Johannes Gutenberg (1398–1468) invented his mechanical movable-type printing press in 1440, the closely connected (visual) activities of writing and reading were engaged in only by the educated, ruling classes. The overwhelmingly illiterate common people's only connection to writing was when it was read aloud to them. They maintained their profane cultures by telling each other stories from within their rich oral/aural traditions and playing instrumental music. Gutenberg's invention flooded Europe with printed material. It made the Bible more available and encouraged an increase in literacy rates which eventually resulted in dissent from the Roman church's authority in the form of the sixteenth century's Protestant Reformation. The spread of literacy was accelerated by the emphasis on formal education and made way in the seventeenth century for an intellectual rebirth in Europe in the form of the Renaissance which eventually lead, over an extended eighteenth century, to the Age of Enlightenment in which reason was advocated as a means of establishing an authoritative system of government, religion, ethics and aesthetics. This supported an intellectual and scientific impetus to obtain objective truths about the whole of reality, the spread of learning to the masses, and laid the material basis for modern knowledge-based economies.

Breaking the mental clutches that the church imposed by leveraging illiteracy and the use of sound to surround and sublimate independent voices, required (men) of vision, using empirical techniques, to "look" outside the religious dogma of the church for objective theories of the natural world "out there". It also required the invention of observational instruments and techniques "favorable to the progress of the arts and sciences" [20, p227]. For example, Galileo Galilei (1564-1642) built his own telescope in 1609, a year after it was patented in the Netherlands [15, p15]. Another such invention was the (re)discovery of the laws of linear perspective by the Filippo Brunelleschi of Florence (1387-1446) which enabled the depiction of visual depth on a planar surface. Lacking a theory of mathematical perspective, artists of the Middle Ages were more concerned with the static depiction all-encompassing religious or spiritual metaphors rather than depicting the real, physical world oriented towards an individual viewer.

In parallel to these advances in visual representation, the dominance of angelic voice-only sacred monophonic plainchants of the church were challenged by, and eventually subsumed into, the polyphonic complexities of the compositions of increasingly individually-recognized composers who, in composing order on the cathedral-induced echoic aural incoherence of multiple overlapping lines of the chants, explored, notated and extemporized new musical structures. These structures were not arbitrarily abstract however, but developed from careful attention to both the sounds and accents of the words being sung as well as their meaning in the texts.

4. MUSIC AS LANGUAGE AND RHETORIC

The belief, that since music is a language and can be consciously treated as such, is not confined to post-medieval Europe. Many cultures have developed melodic and rhythmic modes and dance gestures through which associated concrete meanings and/or affective states were communicated to understanding audiences. For example, the ragas and talas and mudras of classical India are used to clearly communicate specific ideas, events, actions, or creatures. The ancient Greeks had invented a whole systematic theory of how different musical elements affect the soul in different ways. The Renaissance of their ideals in Europe included the application of rhetorical devices, not only in speech, but in music and dance. A system of rhetorical devices, i.e. a representational vocabulary for making communication explicable and persuasive, was considered essential for organizing the syntax of (initially voice-only) compositions and, by addressing an audience's logical and emotional dimensions simultaneously; made the music semantically effective and thus able to communicate successfully. By the middle of the sixteenth century, such rhetorical devices had developed into often extravagant musical word paintings or madrigalisms as they were known. Nevertheless, the study and use of rhetoric to make musical discourse meaningful continued through the seventeenth and well into the eighteenth century. Haydn, often described by his contemporaries as "a clever orator" and "the Shakespeare of music," is probably the last major European composer whose music was regularly discussed by his contemporaries in terms derived from the classical tradition of rhetoric [2], [19].

5. THE RISE OF ABSTRACT INSTRUMENTAL MUSIC

During the Middle Ages, secular music consisted of heroic and lyrical minstrel songs and instrumental music to accompany dancing. During the Renaissance, the Church's attempted to suppress most forms of instrumental music as profane failed as regal courts became significant centers of social, economic and cultural economic activity outside of Church [4]. As monarchs and their courtiers required intellectual stimulation and entertainment, the composers serving in the courts became more experimental, using a widened variety of musical instruments, increasingly considered musical forms as modes of personal expression. These forms became increasingly non-rhetorically-referential to written or spoken texts. While initially following in the spirit of courtly dances, the decline on the reliance of textual subjects in favor of formal reflexivity [10, p94] became a means of embodying aesthetic affects.

As a consequence, there arose a belief that music was not a language in the sense that it no longer had properties of defining and referring to specific meanings about which interpretations and responses could be made. The need for some understanding of what we might call the semiological codes of music was apparent however, for without them it would have been difficult to claim for music to be no more than beautiful arrangements rather than important expressions of human experience and expression in the humanist tradition. In discussing musical language, Alan Durant [8, p10] says:

> *On the one hand, there is 'language' as an assumed range of properties and associated effects, determined ... by psychological or acoustical resources. These supply continuity for the 'language' and an overall framework for activity. Music made outside the framework is simply part of another 'language'. What would be most interesting about this 'language' would be the precise nature of the acoustic and psychological resources, even if these–failing some way of determining correspondences between forms and effects–will not explain very much about actual, particular pieces of music. In the other emphasis, there is language as a set of properties and associated effects (still conditioned by psychological and acoustic resources), whose most significant features are those of social, regional and historical variation around those resources.*

And later (op. cit., pp 13-14), recalling Claude Debussy's "Works of art make rules but rules do not make works of art" [17, p590], he observes:

> *...In this latter emphasis, musical works do not simply exist within, or use, the musical 'language': they make and remake it, in particular realizations and directions of potential.*

Following the rise of public concerts and music to be listened to for its own sake, the status of instrumental music grew in the eighteenth century, as did the Cartesian idea that abstract reflexive forms were the pre-eminent *raison d'être* of musical expression, so that "critics increasingly came to think of music as having emancipated itself from mimetic representation" [10:189]

6. "ORGANIZING THE DELIRIUM"

During the nineteenth and early twentieth century, there was a shift by composers from musically representing various gestural and aesthetic affects (as portrayed in the different formal dance forms, for example) to the representation of individuals' changing emotional states. The principal structural means of organizing both moment-to-moment flow within a work as well as the form of the entire composition was functional tonal harmony, which relies on a set of codes or functions to create expectations in the listener of, given what has just occurred, what might occur next. The German Romantic interest in the personal expression of intense emotional states led some composers to search for new expressive means such as rapidly shifting modulations and eventually the abandonment of functional harmony as means of organizing both moment-to-moment flow within a work as well as the form of the entire composition–and eventually of tonality itself.

In addition to its social and cultural imperatives, there arose a distinct trend for Western composers to conceive of their music as complex-patterned time-ordered series of acoustic events that vary in pitch, loudness and timbre; that are absorbed and elicit emotions when listened to. This paradigm is embedded in scored compositions that are abstractly composed and transmitted to listeners by expert musicians. Following the examples of the second Viennese school in the first part of the twentieth century, many composers used serial procedures based on permutation group orderings of the chromatic pitch gamut. This led to a short but intense period when each of the (now "parameterized") dimensions of a composition (pitch,

duration, dynamics and timbre) were all serially organized. This idea of music as a variable-parameterized space has been adopted by sonifiers engaged in parameter-mapping sonification (PMSon).

The composer/architect Iannis Xenakis, whose oblique contribution to sonification is discussed later, was clear that the serialists had made an important contribution to the search for new methods of organizing music by introducing abstraction.However, he did not agree with their declared necessity for using just serial techniques to organize musical material and was critical of linearity of serial thinking: the way pitch dominated musical structuring, even when its influence on the sound was only secondary; that under serialism as they defined it, duration was, in general, even less structurally organized than in traditional forms, and that the resulting disjunct linear polyphony destroys itself by its very complexity [24, p193].

7. FROM PROGRAM MUSIC TO PROGRAMMED MUSIC

Not all composers were caught up in the psychological angst afflicting the German romantics and expressionists, or the following existential modernist's position that ordinary musical listening was archaic and needed to be replaced with "structural listening" [9, p20]. So, the need to concretely "ground" musical expression in the earthly domain persisted in compositional references to the real, often rustic, world. In fact, compositions depicting nature in one way or another were so common that the term *Pastoral* is used as a description of a type of composition, and there are a number of recognized national Pastoralist schools.

Whilst over the last several centuries most aestheticians regarded depictions of birdcalls and battles in music as a debasement of the art, they were popular with the public, as were–and are–nature *atmospheres* such as Antonio Vivaldi's *Four Seasons* (1725), Ottorino Respighi *Pines of Rome* (1917), and Charles Ives, *Three Places in New England* (1912-16). In fact, a compiled list of such works would include many of the best know works in the Western classical canon.

7.1.1. Although less common, the literal transcription of real-world sounds into music has been even more challenging to the abstract expressionists than Pastoral music. The cuckoo calls in Beethoven's Sixth Symphony (1808) and Olivier Messiaen's use of a wind machine in *Des Canyons aux étoiles* (1974) are obvious examples but the trend extended throughout the twentieth century with the inclusion of non-traditional sounds such as the fire siren in Edgard Varese's *Ameriques* (1921), the futurist's noise art and then, especially following the invention of the tape recorder in the 1940's, by *musique concrète*–the term itself being coined by Pierre Schaeffer to contrast the music he was making at *Radiodiffusion Française* in Paris with the "pure" (i.e. abstract) music of the period, especially that being produced by the German expressionist composers including those at the Westdeutscher Rundfunk (WDR) in Cologne. Schaeffer and others established the Groupe de Recherches de Musique Concrète, Club d 'Essai de la Radiodiffusion-Télévision Française (GRMC- at RTF) in Paris in 1951 which attracted many notable composers of the period. He went on to establish the Groupe de Recherches Musicales (GRM) one of several theoretical and experimental groups unified by the study of audiovisual communication and mass media.

8. ALGORITHMIC COMPOSITION AND DATA SONIFICATION

Xenakis' use of mathematics in composition included the application of group theory, game theory, symbolic logic and stochastics [24] was seminal in establishing a compositional "style" known as algorithmic composition which sowed the seed for the idea of representing abstract data relations in sound for investigative purposes. Xenakis was a participant at GRM but, following Schaeffer's refusal in 1963 to use mathematics and the computer in the studio there, established Centre d'Etudes de Mathématique et Automatique Musicales (Center for Mathematical and Automatic Musical StudiesCEMAMu specifically in order to undertake research into the application of mathematical ideas to music composition.

The other notable early algorithmic music research of the period was by Lejaren Hiller and Leonard Isaacson at the University of Illinois at Urbana-Champaign. They used university's ILLIAC I computer to develop a "rules-based" system to create *cantus firmi*, four-voice harmonies, various rhythmic and dynamic schemes, and Markovian stochastic grammars which they realized in the *Illiac Suite* for string quartet in 1957 [13].

Such computational proceduralism developed rapidly during the second half of the twentieth century in league with the rise of cybernetics and cognitive science. The technical feasibility of being able to accurately repeat the synthesis of sounds by digital means enabled the birth of computer music, which was also heavily influenced by the "acoustic event" paradigm that became embedded in many of the compositional software tools used to create it. These tools have been widely adopted by researchers who use them in an attempt to obtain a better understanding or appreciation of relations in datasets of various sizes, dimensions and complexities–what is now called scientific sonification.

It is useful to distinguish data sonifications made for the purpose of facilitating the communication or interpretation of relational information in data, and data-driven music composition, ambient soundscapes and the like—the primary purpose of which is personal expression and other broader cultural considerations, whatever they may be. While scientific or pragmatic data sonifications and music compositions share a common reliance on the need to render structures and relations into sound, their purpose is often different, and so too the rationale for the evaluation of the sonic results. The current use of the term *sonification* to include such cultural concerns is somewhat unfortunate because it blurs purposeful distinctions. A desire to maintain these distinctions is not to suggest that there are not commonalities–the two activities can provide insights that are mutually beneficial. However, because the purposes of the activities are different, so too will be their epistemological imperatives and consequences, such as, for example, in the representational methodologies employed, in tool design, in user-interface and usability requirements and evaluation.

9. PURPOSEFUL LISTENING: MUSIC AND SONIFICATION

There is no one-way, or reason, to listen to music. Even different musics have different contexts and thus require different ways of listening that may involve whole complexes of social dimensions that are simply not relevant to the perceptualization of data relations for pragmatic purposes. Furthermore, though music may be composed of syntactic structures, there is no universal requirement that these structures be made explicit, even aurally coherent. In fact, stylistic or even dramatic considerations may require the exact opposite–in the orchestration of spectral mixtures by melding of instrumental timbres, for example.

In contrast, clarity in information sonification is essential and rendering techniques that produce a kind of "aural gumbo" can be more successful. Consequently, sonifications in which the user-driven real-time exploration of datasets using dynamic scaling in multiple dimensions, perhaps with auditory beacons [14, pp 185-221], may not result in what is currently understood to be musically coherent sound streams. Even if listened to as music, information sonifications may provoke critical commentary about musical issues such as the appropriateness or formal incompleteness of the resulting sonic experience. Perhaps, as Paul Polansky suggested, the closest point of contact between pragmatic data sonification and musical sonification is in compositions in which a composer intends to "manifest" mathematical or other formal processes [18]. This "classical" algorithmic motivation is explicitly enunciated by Xenakis in his seminal book, Formalized Music [24] and many of the cultural concerns in his thesis defense [23].

While numerous composers use mapping and other procedural techniques of one kind or another in their musical compositions, they are rarely interested in "featuring" the mapping explicitly. Nor do they use mapping in order to simplify the working process or to improve production efficiency, but in order to craft the emergence of musical forms. In order to gain a deeper insight into the way composers map conceptual gestures into musical gestures, Paul Doornbusch surveyed a select few composers who employ the practice in algorithmic composition [7, pp. 145-156].

> *I am not interested in projecting the properties of some mathematical model on to some audible phenomena in such a way that the model be recognized as the generator of some musical shape.*

So, those interested in producing music of a certain complexity may shy away from simple mappings as they can be hard to integrate with other musical material of a substantial nature. On the other hand, as Larry Polansky explains,

> *…the cognitive weight of complex mappings degenerates rapidly and nonlinearly such that beyond a certain point, everything is just 'complex'.*

Even a suitably complex, structurally coherent mapping may not be musically sufficient if the composition relies on a (human) performer, as composer Richard Barrett (in ibid.) emphasizes:

> *In a score one is always dealing with the relatively small number of parameters which can be recorded in notation, and which interact with an interpreter to produce a complex, 'living' result.*

The importance of this embodied "living" aspect of music has often been forgotten, ignored, or even dismissed in many discussions of Western art music, including by some composers. While there are historical reasons for and consequences of doing so, such an approach to data sonification could have a major impact on the intelligibility of computer-rendered mapping-encoded artifacts.

10. MUSICAL NOTATION AS REPRESENTATION

In the evolution of Western art music, notation evolved, along with the notion of the *work*, from a performer's *aides-mémoire* to a tool of thought for defining works of increasingly abstract complexity [11]. Notated scores came to be thought of as the encoded representation of sounds, even as a somewhat definitive objectification of a composer's thoughts. That we (at least in English) so frequently substitute the word 'note' for 'tone', 'music' for 'score', exemplifies the strength of this conceptual elision. Indeed, in a number of intricately notated works of the twentieth century, it seems the performer is sometimes considered an unfortunate necessity. In others, notation functions as encapsulated stimuli by which the performers, as they attempt the impossible task of playing it "note-perfectly", enact a drama of physical and mental exertions. Theodore Adorno noted a tendency to consider the bodily presence of the performer as a kind of contamination of musical experience, as a manifestation of a commodity fetishism where the "…immaculate performance … presents the work as already complete from the very first note. The performance sounds like its own phonograph record" [1].

Occidental art music today encompasses a wide range of motivations and listening practices, and reducing the intelligibility of such music to the conceptual level of scores and instruments has enabled an unprecedented level of complexity. However, there is a growing recognition among music researchers, supported by a significant body of research in neuroscience, that the conveyance of this complexity is reliant, at least to some extent, on embodied interpretation for effective communication [12]. It was not until it was technically possible to construct musical compositions without the assistance of embodied interpreters that it was possible to meaningfully speculate on the extent to which a listener's perception of the structural characteristics of a piece of music are dependent on the sound-encoded gestures of performers, and not just the notated score. This has the unfortunate consequence that if sonifiers think of data as being the sonification equivalent of a parameterized musical score and follow the path of least resistance, as most have been apt to do, use composition software designed to produce abstract musical objects, their sonifications will lack the intelligence carrying capacity that is recognized as embodied in the (often micro-) gestures of musical performers. [22, pp. 52-59].

This should act as a caution that, while adopting tools of one domain into another can be a very empowering, such adoption does not come value-free. If the intelligibility of much music is bound, not only to text, rhetoric, metaphor and formal devices such as phrase structure and the semantics of harmonic tension and resolution, but to the transmission through sound of the embodied foreknowledge of performers, in establishing the foundations for the practice of information sonification, it is sensible to

embrace approaches to forming sounds and their relationships that are supported, yet as unencumbered as possible, by the conceptual boundaries placed by tools for computer music-making as they currently exist. This in-turn has the potential to enrich the practices for which the tools were originally meant.

Sounds and sonic structures demonstrate their weak proclivity to bind to casual inferences [6, p108-109] and strongly to metaphorical representations: From the rustle of dried leaves caused by escaping prey to the echoic resonances of a cathedral and a crowded street; from the phonetic structures of speech to word-painting in Renaissance madrigals; from musical rhetoric and Pastorals to instrumental expressions of affective states; from the turbulence of gas molecules to gravity waves and the folding and cracking of the earth's crust; from the movement of objects relative to each other to the flow of data through a network. With careful attention to sonic details and their relationships to each other in context; to the isomorphic-heteromorphic bindings between sounds and their causes, sonification can more powerfully render vibrant voices for unseeable things.

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