Sonifying the Higgs:
Choice and Coding Orientation in the Recontextualization of Quantitative Data

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La musique est dans tout. Un hymne sort du monde.
Victor Hugo
From "Écrit sur la plinthe d'un bas-relief antique," *Les Contemplations* (1856)

Introduction

On July 4, 2012, the European Organization for Nuclear Research (CERN) announced the discovery of a Higgs-like particle (CERN, 2012). The announcement was greeted with enthusiasm by the high-energy physics community and by the popular press. Data from CERN's Large Hadron Collider (LHC) provided some of the most compelling evidence theretofore for the existence of the Higgs boson, a fundamental particle popularly known as the 'God Particle' (see Lederman & Teresi, 1994) and a manifestation of the Higgs field, hypothesized to give other fundamental particles their mass (see Bernstein, 1974; Cham, 2014; and Higgs, 2010, *inter alia*, for histories and explanations of the Higgs).[1]

A team of researchers, led by physicist and composer Domenico Vicinanza, translated the LHC data from CERN into a score and a series of audio recordings that were widely reported and presented in the popular press at the time, under headlines such as "The Higgs Boson Sings!" (Locker, 2012), "Scientists Set the Higgs Boson to Music" (Knapp, 2012), and "Here's What the Higgs Boson Sounds Like" (Garber, 2012). In this paper, I explore, through social semiotics and systemic-functional theory, some of the choices made in creating a score from the LHC data and in translating the score into sound. More specifically, I ask: What choices has the composer made? What motivated those particular choices? Are some choices—i.e.

[1] A press release on March 14, 2013 (CERN, 2013) announced that new data "strongly indicate" that the particle detected in 2012 was the Higgs boson.

the options available and the actual selections made—more highly valued than others? And, if so, why and by whom?

The primary material for this study comprises Vicinanza's score (see Figure 1) and audio recordings of performances of this score (https://soundcloud.com/lhcopensymphony), as well as a visual representation of the LHC data, published by CERN (see Figure 2).[2] I also draw upon notes from a brief interview I conducted with Vicinanza in August 2013, as well as material from the website LHC Open Symphony (Vicinanza, 2012).

Figure 1. Score based on data from CERN. The high C (C7) in bar 2 corresponds to the predicted mass of the Higgs boson (cf. Figure 2). Image courtesy of Domenico Vicinanza.

[2] Additional audio recordings, made for the purposes of this paper, can be accessed at www.danielleesfryer.com/DLF/Higgs.html. References to these recordings are marked in the text by the symbol 🔉.

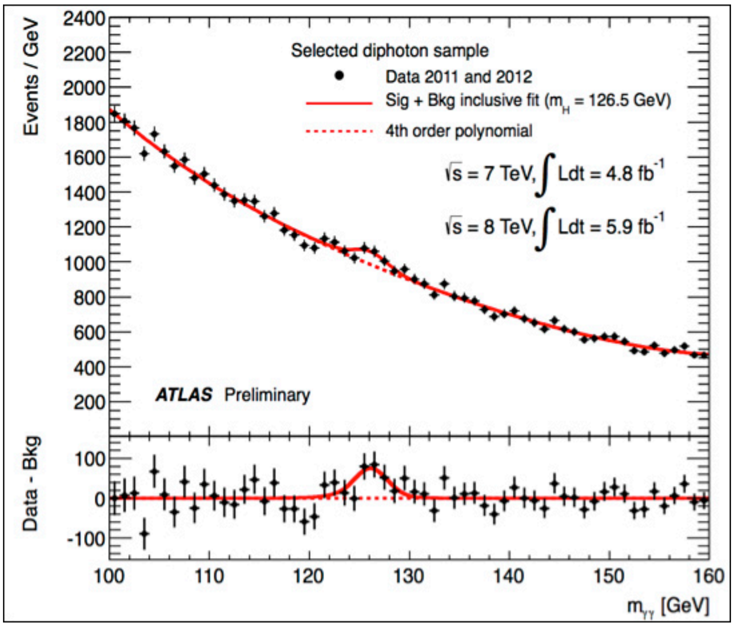

Figure 2. Line graph based on data from CERN. Data points around 126 GeV (the 'bump' in the graph) correspond to the predicted mass of the Higgs boson (cf. Figure 1). Image courtesy of ATLAS Experiment © 2014 CERN.

Recontextualization

The score and the audio recordings are the result of a complex set of processes in which, from a social-semiotic perspective, meaning-material is moved or translated across contexts; for example, from the 'real-world' artifacts and actions at CERN—e.g. the particles, the collisions, and the byproducts of those collisions—through the recordings and measurements of those artifacts and actions, to their visual and audio re-presentation (see Figure 3). As part of this re-presentation, or recontextualization (cf. Bernstein, 1996), meaning-material is translated from one context, with its particular social organization and particular mode or modal ensemble, to another context, with a different social organization and potentially different mode or modal ensemble (Bezemer & Kress, 2008).[3]

[3] Kress (2003, 2010) uses the term 'translation' to refer to the general movement of meaning-material. He further distinguishes between movement *within* and movement *across* semiotic modes, as 'transformation' and 'transduction,' respectively. While the recontextualization discussed in this paper likely involves a variety of transformations and transductions, Figure 3 simplifies these processes in terms of a limited set of major transductions.

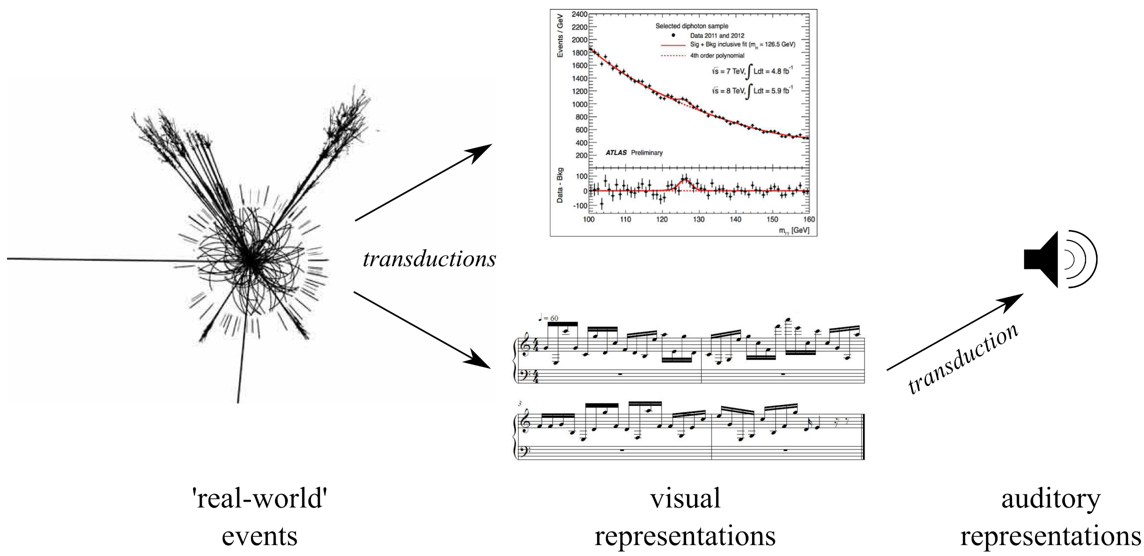

Figure 3. Recontextualizing the events in the LHC: simplified figure showing the translation, or transduction (Kress, 2003, 2010), of meaning-material across semiotic modes. Images courtesy of ATLAS Experiment © 2014 CERN and Domenico Vicinanza.

For Bezemer & Kress (2008, pp. 184–186), recontextualization implies a number of decisions or choices about what meaning-material to select from the originating context and how that meaning-material can be translated or re-presented in a new context. Recontextualization also implies decisions or choices about how to arrange meaning-material in the new context, and about which elements are to be foregrounded or backgrounded. These decisions or choices depend, among other things, on the translator's interests and motivations for the recontextualization, on the kinds of social relations enacted in the originating and new contexts, and on what modal resources are available (or deemed most relevant) in the new context.

Choice and Coding Orientation

Choice is a key concept in systemic-functional theory (see, for example, Fontaine, Bartlett, & O'Grady, 2013; Halliday, 2002 [1963]; Matthiessen, Teruya, & Lam, 2010). It is central to a paradigmatic and probabilistic view of language and other meaning-making resources, in which semiotic systems, and the options within those systems, represent a semiotic potential—a potential for meaning-making—in a particular eco-social environment. What is chosen and what is not chosen but could have been (as well as "what is chosen not to be chosen") are part of the meaning of a particular instance of choice (Halliday, 2013, pp. 25–26).

In order to comment on the types of choices made for the Higgs composition and audio recordings, I refer to Bernstein's (1981) notion of code, a regulative principle that selects and integrates relevant meanings, the forms in which those meanings are realized, and their evoking contexts (Bernstein, 1981, pp. 328–329). Crucially, with regard to choice, and in particular with regard to what is not chosen, "code presupposes a concept of irrelevant or illegitimate meanings; […] inappropriate or illegitimate forms of realization; [… and] inappropriate, illegitimate contexts" (Bernstein, 1981, p. 329).

Kress & van Leeuwen (1996, 2006) and van Leeuwen (1999) describe sets of regulative principles, or 'coding orientations,' based on Bernstein (1981), that attempt to account for how certain texts are encoded by different social groups or in specific institutional contexts, i.e. the particular values associated with semiotic choice (van Leeuwen, 1999, p. 160). Van Leeuwen (1999, pp. 177–180) suggests three general coding orientations for sound:

1. A 'naturalistic' coding orientation holds that sounds should articulate as closely as possible some form of natural reality, that they should not be "dramatized and emotionalized, but judged on the basis of what is considered 'normal' and 'everyday'" (van Leeuwen, 1999, p. 179). Van Leeuwen cites modern cinema as an example, where sounds or sound effects (but not usually soundtracks) are generally expected to represent their sources in as naturalistic or imitative way as possible.
2. An 'abstract-sensory' coding orientation maintains that sounds articulate the essence of what they represent, as something abstracted and generalizable. For van Leeuwen (1999, p. 177), music is the most abstract form of sound, but this abstraction is one that is also sensory or emotive, where parameters such as pitch and duration can be adjusted—usually within relatively fixed and/or limited ranges and intervals—and can create different emotional responses, as might be the case in, say, classical music (van Leeuwen, 1999, p. 178).
3. In a 'sensory' coding orientation, however, the emotive or sensory takes precedence, favoring (in comparison with the other two coding orientations) a 'more-than-real' representation (van Leeuwen, 1999, p. 179). A greater range of pitch and duration allows for exaggerated effect and potentially greater

emotional impact, like the gong-like sound of a frying pan in slapstick comedy.

Sonification

Before discussing the Higgs sonification, it is important to note that sonification, or auditory display, is a relatively well-established concept, one that draws in various ways on the fields of “audio engineering, audiology, computer science, informatics, linguistics, mathematics, music, psychology, and telecommunications” (Walker & Nees, 2011, p. 9). It deals with the “technique of rendering sound in response to data and interactions” (Hermann, Hunt, & Neuhoff, 2011, p. 1), and can be defined as “the use of non-speech audio to convey information” by “the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation” (Kramer et al., 1999, n.p.). Moreover, this process of transformation, Hermann (2008, p. 2) and Walker & Nees (2011, p. 9) say, should be “systematic, objective and reproducible.” Common applications of the sonification technique include the Gieger-Müller tube for detecting certain types of ionizing radiation and cardiac monitors used in hospitals—both of which are based on real-time or synchronous quantitative data—as well as more novel applications such as teaching data-literacy in school science and mathematics classes (Upson, 2001).

Choice and the Higgs Sonification

In the case of the Higgs sonification, I begin by discussing some of the choices the composer has made in creating the visual score and audio recordings. I group the discussion of these choices—what was chosen and what was not chosen but could have been—loosely into pitch, timbre, duration, and intensity, acknowledging that some of these categories overlap, that some of the choices or selections discussed are not necessarily conscious ones, and that the availability and selection of certain choices will be conditional or contingent upon other selections (Halliday, 2003 [1995], pp. 410–411).

I have made audio recordings that exemplify some of the instances of choice that, in the original Higgs audio recording, were not chosen but could have been. These audio recordings are indicated in the text by the symbol 🔉 and can be accessed at www.danielleesfryer.com/DLF/Higgs.html.

Pitch

Pitch relates to the frequency of sound, and variations in pitch are associated with melody. For the Higgs sonification (see Figure 1), pitch and pitch intervals are determined by the choice of tuning system: twelve-tone equal temperament, in this case. The piece is in the key of C, and the composer and his team match the LHC data to individual notes within that key (C, D, E, F, G, A, B) using the following algorithm:

> 1. the same number [in the data] is associated to the same note
> 2. the melody is 'covariant' with the data, i.e. the melody changes following exactly the same profile of the scientific data
> (Vicinanza, 2012)

As the composer states, "I used a linear mapping from the initial data set to a set of music notes within a scale (instead of just mapping to frequency)" (Vicinanza, 2013). Here, Vicinanza not only makes explicit his actual choice, the mapping of data on to a specific set of notes; he also acknowledges a particular option that was available to him, one that was not chosen but could have been, and possibly one that was chosen not to be chosen (cf. Halliday, 2013, pp. 25–26), namely the rejection of any particular tuning system.🔉 The selection of twelve-tone equal temperament and the C-major scale can be contrasted with options of different tuning systems and different keys, although these are arguably the most recognizable or familiar choices from a popular or classical music perspective.

Other pitch-related options might include the relative discreteness of individual notes. The intervals between notes are determined by the chosen scale (see above), but a gliding effect, a glissando or portamento, could have been applied to connect the notes in a way that might have given the sonification a 'line of fit,' similar to that in Figure 2, from which one might infer relationships between data points.[4] 🔉

[4] Gliding (or the extent of gliding) depends, of course, on the sound source. Unfretted string instruments such as violins and cellos have little problem creating such effects; it is somewhat more difficult, however, for an instrument like a piano (see comments on timbre).

Timbre

Timbre refers to the quality of sound, and is determined by the overtones and sound envelope produced by a particular instrument or sound source. Timbre is essentially what distinguishes one sound from another, or one sound source from another, when two sounds have the same pitch, duration, and intensity, e.g. the difference between a middle C of equal length and loudness played on a piano compared with a guitar. For the Higgs sonification, the score is performed on a piano, a Bösendorfer (https://soundcloud.com/lhcopensymphony), an instrument whose timbre, at least when played with standard techniques, will be familiar to many listeners. Indeed, the composer justifies this particular choice as being “something recognizable to stress the fact that the final result is something that anybody can play, not just a computer” (Vicinanza, 2013). This invites the question of what alternative timbre-related options were available to the composer. Might the familiarity of the piano be replaced by other familiar stringed, percussive, or electronic instruments, such as an electric guitar?[5] This is an important question if one considers the extent to which a particular sound, or timbre, might best represent the data from CERN, particularly the data that correspond to the Higgs boson. The sound of a piano is arguably so distinctive or familiar that it first and foremost presents or denotes itself, the sound source. This seems to be partly reflected in popular-press headlines such as “The Higgs Boson Sings!” (Locker, 2012) and “Here’s What the Higgs Boson Sounds Like” (Garber, 2012).[6] But what do data actually sound like? Can numerical data be sources of sound in themselves, or do they need to be represented or connoted through other means? Sound or sounds from the experimental environment at CERN, for example, could be recorded and used to present the data, as a form of *musique concrète* (Schaeffer, 2012 [1952]) or naturalistic soundscape (Schafer, 1994 [1977]),

[5] Different social groups are likely to have different levels of familiarity and accord different values to different instruments or sound sources. In the example mentioned here, the sound of an electric guitar may be more familiar to and/or more highly valued by certain social groups than the sound produced by a concert piano. There is an example of this in Barthes’ “Musica Practica” (Barthes, 1977, pp. 149–150), where Barthes, writing in 1970, notes the decline of the piano as a source of practical music in the West, in comparison with the instrument of choice of the “young generation,” the guitar. The same type of comparison might be made today with regard to the guitar and certain forms of electronic composition and performance. Clearly, the familiarity and values attributed to different sounds and sound sources are subject to sociohistorical change.

[6] These headlines may also refer to the pitch or frequency (and to the duration and intensity, for that matter) of the note that represents the Higgs data, the high-pitched C7 in bar 2 of Figure 1, rather than (or in addition to) the timbre of the sound source in the audio recording.

but the timbre of those sounds would not necessarily denote the Higgs as sound source, nor would they denote the numerical data collected during the experiments.

Another timbre-related option is the choice of a more abstract sound, for example sine waves. The lack of overtones in pure sine waves might allow for an easier ‘reading’ or representation of individual data points, particularly if one maps to frequency (see comments in Pitch section above). Moreover, their use in scientific or technological applications could connote a more “objective” representation (cf. Hermann, 2008, p. 2; Walker & Nees, 2011, p. 9) compared with a piano or other familiar music instrument, and might potentially disrupt the interpretive relation between the sound and the kind of source that generates it. A piano sound, we generally assume, is made by a piano; it presents the piano as the source of that sound. But sine waves can be generated in a number of ways, and may not be directly associated with specific sound sources. That being said, sine waves are often computer generated, and this is an option the composer explicitly chooses to avoid for reasons of familiarity and performability (see above).

Duration

Duration refers to the lengths of individual and combined sounds, to tempo, and to the patterns of sound associated with rhythm. The Higgs sonification is in measured, metronomic time, comprising four bars, of four beats to a bar (4/4), at a tempo of 60 beats per minute (bpm) (see Figure 1).[7] All the notes (bar the last) are sixteenths or semiquavers, and all are equally spaced.

With regard to some of these choices, the composer explains that “60bpm is close to the heart beat, giving a music pulse which sounds immediately ‘familiar’, comfortable” (Vicinanza, 2013). Moreover, says Vicinanza, “I wanted something describing the data without adding too much, so I have chosen a regular rhythm, just associating each note to a semiquaver” (Vicinanza, 2013).

One of the greatest challenges with regard to duration, and perhaps with regard to the use of sound in general, is the fact that, while sound has an obvious temporal aspect—

[7] Note that the audio recordings are performed at approximately 80 bpm (https://soundcloud.com/lhcopensymphony).

it unfolds over time—this is more or less absent from the LHC data. Although the data were collected from experiments over a two-year period, the two main data variables are the number of collision events recorded and the masses of those particular events (see axis labels in Figure 2). The Higgs sonification comprises 46 notes, representing 46 data points or data groups. It is a relatively short piece of music, lasting approximately 10 seconds in the case of the piano recording (https://soundcloud.com/lhcopensymphony).[8] An interpretative possibility here is that the duration of the piece somehow represents a chronology of events, from the moment of collision to the detection or measurement of individual events. In the piano recording, the occurrence of the note representing the mass of the Higgs boson, the C7 (see Figure 1), might suggest a time from collision to manifestation of approximately 3.5 seconds, or a relation of 3.5:10 if the real-life events are understood to occur within a shorter timeframe than that indicated by the sonification. Time is, of course, an unavoidable affordance, an epistemological commitment (Kress, 2003, p. 3) imposed on the translator by the mode itself. Such interpretations are therefore difficult or impossible to avoid. But what effect might an increase or decrease in tempo have on this possible interpretation? At 1000 bpm, for example, the piano piece is heard as a cluster of notes occurring more or less simultaneously, but with the C7 still audible as a distinct note. Such a choice rules out the 3.5-seconds-to-manifestation interpretation, suggesting instead, perhaps, a set of events that occur more or less instantaneously. However, this choice would be at the expense of being able to discern individual notes and the relations between those notes, and the ways those notes and relations represent the data. Moreover, the piece loses the possible 'familiarity and comfort' that the composer attributes to a tempo of 60-80 bpm (see comments above).

In addition to tempo, many choices are available for time signature and note divisions, some of which might be considered relatively standard choices in classical or popular music, such as a 3/4 time signature or the use of eighths and tuplets instead of (or in addition to) sixteenths. Another duration-related option is sustain, which might have

[8] The orchestrated version of the Higgs sonification (https://soundcloud.com/lhcopensymphony), featuring piano, double bass, flute, marimba, and other percussive instruments, lasts approximately 3 minutes, with the central 10-second phrase of the Higgs score repeated several times.

emphasized the relations between contiguous notes as well as the measured background signal, which is roughly equivalent to E4 (see Figure 1).

Intensity

Intensity refers to the amplitude or loudness of sounds. In the Higgs sonification, the intensity of sounds is fixed or static. The score does not provide dynamic marks, but the piano in the audio recording is played at more or less the same level of loudness. In the orchestrated version (https://soundcloud.com/lhcopensymphony), the intensity of sounds is more dynamic, as different instrumentations overlap and combine.

A number of choices with regard to intensity were potentially available to the composer, although one might argue that these generally add to the description or representation of the data in a way that the composer tries to avoid (see comment above in Duration section). However, varying levels of intensity could have been used to emphasize the Higgs data and to de-emphasize near-background data. For example, greater deviations between data points and the background signal could have been represented by greater levels of intensity, thus highlighting the 'standout' Higgs data.

Coding Orientation and the Higgs Sonification

Before discussing van Leeuwen's (1999) coding orientations for sound, I would like to briefly consider the composer's motivations for the sonification. According to the LHC Open Symphony webpage (Vicinanza, 2012), one of the main aims of the project is to "help people understand or at least 'feel' the complexity and beauty of the finding." The project might also

> […] allow a blind researcher to understand exactly where the Higgs boson peak is and how big the evidence is. At the same time, it could give a musician the opportunity to explore the fascinating world of high-energy physics by playing its wonders. By studying different sonification algorithms we can find more and more effective ways to support researchers to detect interesting phenomena by listening to them. (Vicinanza, 2012)

The social relations enacted in the originating and new contexts are potentially rather different (see Bezemer & Kress, 2008; Martin, 1992, pp. 523–536, among others, for general discussions of social relations and tenor). In the originating contexts, we presumably have an exchange or negotiation primarily among peers, with similar institutional roles, largely within the particle-physics community. In the new contexts, different sets of institutional roles or contact are likely to be enacted, as well as different status roles, particularly with regard to expertise. The new context suggests a wider, possibly lay audience, through various current-affairs magazines such as *Time*, *Forbes*, and *The Atlantic* (see Introduction), but one that simultaneously seems to be aimed at other physicists or researchers, such as those who are blind or partially sighted or those who want to "detect interesting phenomena" in new ways (Vicinanza, 2012).

With these diverse social relations in mind, what regulative principles might have informed the choices made in the Higgs sonification? What are the appropriate or inappropriate, relevant or irrelevant, legitimate or illegitimate choices that these principles, as coding orientations, presuppose? I would suggest, in general, that the Higgs sonification is the result of a hybrid set of regulative principles that are part of an abstract, scientific/technological perspective, on the one hand, and an emotive, sensory ideal, on the other.

According to Kress & van Leeuwen (2006, p. 165), abstract coding orientations are typical of science, academia, "high art," and the interactional practices of certain "sociocultural elites." In such contexts, the individual or specific is extrapolated to the general and the concrete is reduced to its essential qualities (Kress & van Leeuwen, 1996, p. 165; van Leeuwen, 1999, p. 177). In the Higgs sonification, this abstraction is evident in certain decisions to reduce or minimize articulation, for example in adopting an absolute minimal range for the duration of notes (all sixteenths) and for dynamic variability (fixed levels of loudness). It is also evident in comments made by the composer, e.g. "I wanted something describing the data without adding too much" (Vicinanza, 2013), and from the LHC Open Symphony webpage:

> The Higgs sonification is an alternative representation of the scientific graph the ATLAS experiment presented on 4th July. It is following some of the basic principles which guided Pythagoras and many other musician/scientists: harmonies in natural phenomena are related to harmonies in music. A regular, periodic phenomenon is then represented naturally through sonification, by a regular, periodic melody. The sonification algorithm we used offers the same qualitative and quantitative information contained in the graph, only translated into notes. (Vicinanza, 2012)

But certain choices of timbre and pitch, e.g. the use of a piano and 12-tone equal temperament tuning (see relevant sections above), might be considered “inappropriate or illegitimate forms of realization” (Bernstein, 1981, p. 329) in the abstract coding orientation of science, where transformations of data relations into sound are generally expected to be “systematic, objective and reproducible” (Hermann, 2008, p. 2; Walker & Nees, 2011, p. 9). In the case of the orchestrated version of the sonification (https://soundcloud.com/lhcopensymphony), these potentially inappropriate forms become more pronounced as durational variety, dynamic range, and perspectival depth are increased (see van Leeuwen, 1999, pp. 172–174). However, while these choices might conflict with abstract coding orientations, in which articulation is generally minimized, such options are, in contrast, perfectly appropriate and legitimate forms of realization in sensory coding orientations, in which articulation parameters are amplified for increased emotional effect. The importance of this emotive impact is further emphasized by comments from the composer. For example, “this musical interpretation of the LHC data will help people understand or at least ‘feel’ the complexity and beauty of the finding” and, in the case of musicians, allow them to play the “wonders” of high-energy physics (Vicinanza, 2012).

There appears, then, to be a tension or conflict between two coding orientations—between a scientific and objective representation, on the one hand, and an emotive and dramatic representation, on the other—as construed through choices in rendering the LHC data into sound. But are these different choices really contradictory? Might they be compared to the kinds of choices made in certain forms of visual art, in which multiple modality configurations are possible, offering multiple depictions of reality through multiple coding orientations (see Kress & van Leeuwen, 2006, p. 171)? Or better yet, could we compare the Higgs sonification with the way newspapers and popular-science magazines present line graphs and bar charts, adding color and perspective in their recontextualizations of more abstracted, black-and-white, direct-frontal-angle figures from scientific journals?

As van Leeuwen (1999, p. 182) notes, “[m]ixed coding orientations are common in high art practices which question definitions of truth and reality.” The Higgs sonification discussed in this paper may not question truth and reality in the way that high art might be seen to do, but it does attempt to translate a particular truth or reality, a highly abstract and specialized one in the case of the Higgs boson, across potentially divergent social contexts with different coding orientations and thus with different perspectives on what constitutes truth or reality. The Higgs sonification attempts to meet the demands of both coding orientations, reflecting, one might say, a hybridity of scientific and affective truths.

Coda: Hearing Is Believing?

According to Schafer (1994 [1977], p. 10), the ear gave way to the eye, in the West, around the time of the Renaissance, with the development of the printing press and perspective painting. Schafer uses the example of the representation of God as a case in point: prior to the Renaissance, Schafer argues, God was rarely represented visually, and was thought of largely in terms of sound and vibration. Moreover, "[t]he word of God […] was heard, not seen" (Schafer, 1994 [1977], p. 11).

Today, however, seeing is believing. In science, we look at or observe data; we rarely listen to them or hear them. There are exceptions, of course, as attested by the Higgs sonification and various examples from the field of auditory display (see Kramer et al., 1999)—and perhaps sonifications will become more commonplace as some of the choices for rendering data into sound become standardized or more conventionalized (see, for example, Hermann et al., 2011). But the ear still gives way to the eye. Even in the case of the Higgs sonification, and in its reporting and presentation in the popular press (e.g. Garber, 2012; Knapp, 2012; Locker, 2012), the auditory representations of the data, i.e. the audio recordings, are presented alongside a visual representation, the score. Granted, the score is an important part of the sonification—one that, according to the composer, might allow others to more easily reproduce the work—but in all reports, the score is presented first. We are shown what the sounds are based on, visually, before hearing them, as if to legitimize the auditory representation and our experiences of it. The visual, it seems, is given primacy over the auditory, or, to put it another way, the auditory representation plays second fiddle to the visual.

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