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Master Thesis

The Sound of Capta

Sonification as critical method for data perceptualization in digital humanities

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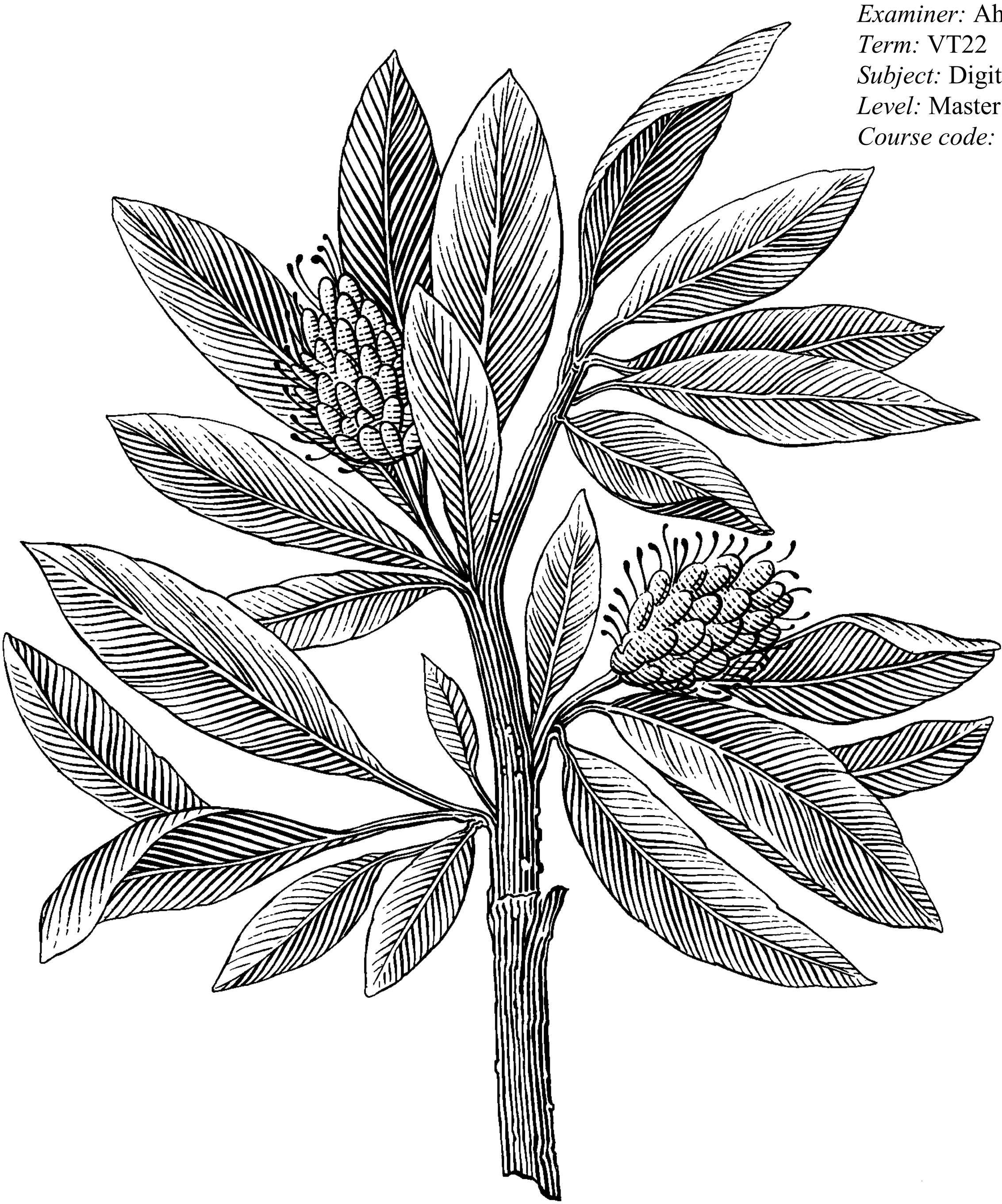

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Abstract

Sonification allows for the analysis and interpretation of data through its rendering into sound. It is a method that remains largely unexplored from a digital humanities perspective. The present thesis addresses this research gap by exploring aspects of sonification as a mode of data perceptualization. Methodologically, it combines an extensive review of sonification literature with the design of a sonification prototype. The prototype is created using an exploratory programming approach and is evaluated through a small user study. One of the main challenges of using sonification within the humanities consists in aligning it with humanistic interpretative and critical modes of inquiry, in the thesis understood through the framework of Johanna Drucker's critical hermeneutics. Another challenge is related to the shortage of existing projects and previous research, and also to a lack of relatively easy-to-use sonification tools. In the thesis, these challenges are primarily made visible through the process of prototype design and through the subsequent user study. Nevertheless, the literature review successfully uncovers a number of potential strategies for the realization of humanistic-interpretative sonification design, focusing especially on the concepts of *phenomenology of listening* and *musical sonification*. By applying musical sonification, it becomes possible to move beyond the simple representation of data, allowing instead for interpretative approaches. The findings presented in the thesis provide foundations for future research into humanities sonification.

Key words

Sonification, Auditory display, Data perceptualization, Epistemology, Digital Humanities, Critical hermeneutics, Humanities data, Spotify, Music history, SuperCollider

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1 Introduction

With increasing amounts of data comes the challenge of finding techniques for making it readable for humans. One common strategy for achieving this is data perceptualization – making data accessible for the human senses through remediation. The most common perceptualization method is information visualization. However, an alternative or complementary method can be found in sonification, which involves using data as the basis for the generation of sound. According to a well-worn definition, “sonification is the use of nonspeech audio to convey information” (G. Kramer et al., 1997, sec. 2). While admittedly peripheral in relation to information visualization, advocates of sonification point to its potential as an alternative in a wide array of disciplines, ranging from theoretical physics and neurology to the social sciences (de Campo, 2009). At the very least, the use of sound has the capacity for allowing novel perspectives on sets of data.

Within the humanities, a multitude of perspectives and interpretative potentials is often a sought after quality. The new perspectives of sonification should therefore be able to offer attractive possibilities. However, while there is an ongoing debate within the digital humanities on how to perceptualize a growing body of data, and while one can perhaps sense a growing interest in sonification, the possibilities inherent in the use of sound remains underexplored. In the existing research, the subjects investigated are diverse and somewhat scattered. These include the sonification of historical records and of works of literature, digitized historical photographs remediated into sound, and sonification in relation to public space. Theoretically, however, there is a common thread running through much of this research, involving the suggestion that sonification can function as a method for challenging the primacy of sight and visual representation. This will allow for novel and sometimes speculative approaches to a material, in which new interpretative possibilities are opened up.

The overall objective of the thesis is to explore sonification as a method for perceptualizing data within the digital humanities. The purpose is to enrich available means for engaging with humanities data. Realizing these aims will need to involve the exploration of both theoretical and practical perspectives. Theoretically, the thesis will aim at aligning existing practices within the larger field of sonification with the critical approach to data representation found within the digital humanities. This will then be put into practice through the design of an exploratory sonification of a musical-historical data set, aiming at providing a preliminary model to serve as inspiration for future humanities sonification projects.

Structurally, apart from the introductory and concluding sections, the thesis is divided into two main parts: one theoretical part, consisting of the extended literature review, and a practical one, involving the exploratory sonification of a large-scale musical data set retrieved from Spotify. These two parts follow progressively on each other, with the sonification design drawing on the findings in the literature review. The chapter on Previous Research will survey existing approaches to sonification within the digital humanities, while the theoretical framework will present critical approaches to data perceptualization as represented by the critical hermeneutics of Johanna Drucker. Both these chapters will delimit and provide points of entry to the extended literature review.

2 Background

2.1 Digital humanities, data, sonification

The digital humanities can be understood as a diverse ecology of scholarship, sometimes described as a “big tent” or an “expanded field” that over time has come to encompass an increasing range of practices and methods. According to Gold and Klein (2016, para. 1), beyond quantitative analyses, tool-building projects and digital archives, contemporary digital humanities also includes “visualizations of large image sets, 3D modeling of historical artifacts, ‘born digital’ dissertations, hashtag activism and the analysis thereof, alternate reality games, mobile makerspaces, and more.” While acknowledging this diversity, it is at the same time possible to argue that one of the core concerns of the digital humanities involves the study, manipulation, analysis, and interpretation of (digital) data (Arnold & Tilton, 2019; Posner, 2015). One of the main reasons for this is that cultural heritage documents and artifacts progressively are being digitized, yielding an ever-expanding quantity of data. But also, the contemporary omnipresence of digital networked technology means that a growing part of what is generally the object of study for the humanities – the traces and records of human culture – is born digital, and thus exists as digital data.

With the increasing amounts of data comes the problem of how to make it accessible for humans for reading and interpretation. One common strategy is perceptualization – that is, to remediate it in a way that makes structures in complex sets of data apparent to one or several human senses. Clearly, the most common form of perceptualization is data visualization, and its use has been extensively discussed and regularly critiqued within the digital humanities community. However, there are also examples of more exotic methods such as sculpturalization, whereby data is rendered into physical form, often with the use of 3D printers. With sonification, the medium of sound is used. Sonification is a category of the wider concept of *auditory display*, which includes many forms of communication through sound, for example in the form of alarms, auditory icons, and voice messaging. For sonification, there are a long range of available definitions given by various practitioners in the field (see for example Barrass, 2012; Hermann, 2008), but one of the most commonly used states that sonification is “the use of nonspeech audio to convey information”, involving “the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation” (G. Kramer et al., 1997, sec. 2).

Historically, as a background, there have been a number of more or less successful attempts at conveying scientific information through sound. The stethoscope is an early example of this. Invented during the first half of the 19th century, it provided medical professionals with a tool for listening directly to the sounds of the body for its informational content, making possible a range of diagnostic practices. A somewhat more recent, and also very successful, example is provided by the Geiger counter. Through the invention of this device in 1928, the presence of radiation, previously discernible only through complex experiments, was made accessible for immediate sensory perception. A perhaps less successful experiment with sonification, carried out in the 1960s, involved an attempt to distinguish normal seismic activity from underground nuclear explosions through the transposition of seismic signals into an audible range. This sonification design was quickly replaced with visual methods that were perceived as more reliant. Nevertheless, it is often perceived as a forerunner to contemporary sonification practices (Supper, 2015; Volmar, 2013).

As can be seen, these examples of early scientific listening technologies functioned through making an already existing signal or sound audible through methods of amplification and/or warping. In contrast, for most present-day sonifying practices, the material basis for sonification designs – the stuff that is made perceptible through rendering into audible form – are patterns in complex sets of data. Indeed, according to Worrall (2019), author of one of few existing books wholly dedicated to the subject of sonification, the aspect that distinguishes sonification from other related practices aimed at transmitting information through sound is that sonification derives its sonic material from the "inherently silent abstractions" of data and variables (p. 23). Since it is in no way self-evident how such abstractions are supposed to sound, it leaves a great deal of creative freedom to sonification designers. For this reason, the practice of sonification has historically drawn – and continues to draw – much inspiration from various types of experimental and data-driven forms of music and sound art. Apart from scientific listening devices such as the Geiger counter, the prehistory of sonification should also include the influence exerted by composers such as Iannis Xenakis and John Cage (Gresham-Lancaster, 2012; Worrall, 2019).

The importance of musical and artistic practices for sonification can also be found in the tools used for the design of sonifications. Given that most contemporary sonifications function by connecting specific features of a set of data with (parameters of) electronic sound synthesis, making the generation of sound dependent on patterns within the data, digital and computational technologies are of crucial importance. Today, there is a range of software applications that have been specifically designed for sonification and auditory display, often in open source or freeware formats. However, these tools have often been developed with a very limited set of tasks in mind. More versatile approaches are made possible through software environments originally designed for artistic practices such as computer music and algorithmic composition. For instance, audio programming languages such as SuperCollider, Pure Data, Max/MSP, and Csound are very popular and commonly used within the sonification community (Bearman & Brown, 2012). These allow for extensive creative freedom on part of the designer. At the same time, it must be noted that such specialized programming languages generally have a very steep learning curve, require a great deal of prior knowledge, and thus risk excluding many people from the practice of sonification design. Perhaps in time, sonification tools that approximate the relatively easy-to-use applications found within data visualization will be developed. From a digital humanities-perspective, the sonification and sound-synthesis packages that are being developed for Python, such as the Sonipy or Python-sonic (Patton, 2020; Python-Sonic 0.4.3, 2021), are possibly of special interest given the strong standing of this programming language within the community.

As can be seen, there exist a diverse variety of tools for sonifying data, and sonification practices draw on many different traditions. But to what extent can the theory and practice of sonification be said to constitute a coherent field and/or community? Historically, the founding moment of the contemporary field of sonification is often said to have taken place with the first International Conference on Auditory Display (ICAD) in 1992. Before this time, the communication between practitioners was disorganized, and the work being done was mostly of a one-off character, scattered across geographic locations and among academic journals within a range of different disciplines. With the launch of ICAD, a home was created for this research. Indeed, on the web page for the International Community for Auditory Display (which, somewhat confusingly, is also abbreviated ICAD), the conference and the community are described as "unique in its singular focus on auditory displays and the array of perception, technology, and application areas that this encompasses" (International Community for Auditory Display, n.d.). To some extent, the history of ICAD can therefore be considered representative of the contemporary history of auditory display as a field (G. Kramer & Walker, 2005). For this reason, the Proceedings of the ICAD conferences have received special attention in this thesis as being the focus of the review of publications on sonification.

Finally, before moving on, the following question needs to be asked: why should (digital) humanists take an interest in sonification? What are its potential benefits when compared to other types of data perceptualization and representation such as information visualization? One possible answer is provided by cognitive science, which has found that non-speech sounds allow for unique perspectives as compared with images and texts (Tversky, 2015). This means that sonic modalities, when contrasted with more traditional methods of representation, make possible novel ways of engaging with and understanding a given set of data. Another answer might be found in the affordances of the human auditory system. In *The Sonification Handbook*, Walker and Nees (2011, p. 11) argue that the auditory system has a superior ability for recognizing "temporal changes and patterns". Consequently, sonification might be especially useful when trying to make perceptible data that involves complex patterns that evolve over time. However, from a humanist perspective, it is far from self-evident that such effective information transmission is necessarily a sought-after quality. Rather, it is perhaps the inherent ambiguity often associated with the medium of sound that should spur interest. According to Worrall (2019), instead of unambiguously transmitting casual relationships, sound is generally more useful for communicating metaphorical representations. In other words, complex non-speech sound tends to be ambiguous, allowing for a multitude of perspectives. According to Tversky (2015, sec. 3), ambiguous representations make perceptible "many possible state of affairs", allowing for "the taking of new perspectives and new interpretations, the foundations of creative thought". As we shall see in the chapter on theory, such an approach of creative interpretation, involving many simultaneous points of view on a singular object of study, is often at the core of humanistic research. Or as Worrall (2019, p. 19), in an evocative and poetic summary of the potentials of sonification, puts it: “...sonification can render vibrant voices for unseeable things.”

2.2 Structure of thesis

Considering that the overall layout of this thesis can be perceived as somewhat unorthodox, a few lines might be necessary for clarifying some points regarding its structural progression. As has been noted above, the thesis is divided into two overarching parts, where two practically focused chapters, describing the design and evaluation of a prototype sonification, follow on a theoretical chapter. The theoretical chapter is based on a literature review covering the field of sonification. This means that there are two literature reviews in this thesis: apart from chapter 3, which covers previous research, a more extensive literature review also appears in chapter 6. These two reviews ultimately serve different purposes: the chapter on previous research is mostly descriptive in nature, covering existing digital humanities research on sonification. In chapter 6 the aim is more ambitious: to develop theory by applying the critical hermeneutics of Johanna Drucker – the theoretical framework of the thesis described in chapter 4 – to a broader range of literature on sonification. The sonification prototype design described in chapter 6 then draws on ideas developed in this extended review. In order to avoid confusing the two reviews, they will be referred to throughout the thesis as *previous research* and as the *extended literature review*, respectively.

Another consequence of the two-part structure of the thesis are that two subchapters dealing with methodological aspects – describing the data set and tools used in the sonification prototype design – have been placed under chapter 7 rather than in the methodology chapter. The idea is to allow for a more coherent presentation of the various aspects of the design process, avoiding a need to jump back and forth in the thesis.

2.3 Note on writing about sound

In this thesis, a range of sonification designs and projects are presented, described and discussed. However, doing sound justice through writing is difficult. This is particularly true regarding complex arrangements of sounds that have duration of several minutes. With this in mind, writing about data sonification is perhaps more difficult than writing about data visualization, given that the latter can easily be exemplified by inserting images into the text. When describing the sound of specific sonification designs, one often has to resort to a specialist language derived from fields such as acoustics, sound engineering, and music theory. This language is often hard to interpret for people unfamiliar with these fields. Therefore, the ambition guiding the writing of this thesis has been to keep descriptions as simple as possible, generally striving to avoid specialist terminology. However, given the number of examples discussed, the writing seldom succeeds in doing the designs justice. Instead, the best way to get a feel for how the sonifications actually sound is to – when possible – listen to them. This can be achieved by examining the individual references and following links to sound resources that are often available, especially in the case of more recent projects. Regarding the description of design of the sonification prototype presented through this thesis, a certain degree of technical language proved inevitable. Hopefully, the writing and the overarching ideas guiding the design will still be possible to follow.

3 Previous Research

The publications covered in this chapter were retrieved during February and March 2022. The methods used include surveying a number of key digital humanities publications (Digital Humanities Quarterly, Digital Scholarship in the Humanities (DSH), Digital Studies / Le champ numérique, Digital Literary Studies, CA: Journal of Cultural Analytics, Journal of Interactive Technology and Pedagogy, Digital Humanities Now). Further, the Linnaeus University Library OneSearch discovery system was utilized, using the following search string: “digital humanities” AND (“sonification” OR “auditory display” OR “audification”) (databases available through the OneSearch system can be found in Appendix 1). Beyond this, lists of references in published material on sonification were surveyed, and, in order to cover the adjacent field of sound studies, a number of handbooks and anthologies covering this field were examined. Finally, taking into account that it is common within the digital humanities to make use of non-conventional modes of scholarly communication such as blogs and social media, general purpose search engines (Google, DuckDuckGo) were utilized in order to cover some extra ground.

To start with, it might be useful to put forward a few general findings. The searches only managed to uncover a relatively small amount of published material that deals with sonification from an explicit digital humanities perspective. While this material is scattered across different projects and digital humanities sub-fields, one can identify a number of key advocates of the practices and theories of sonification, each of which has played a part in several published articles on the subject (most noticeable Shawn Graham, Michael Kramer and Iain Emsley). Much of the expressed interest is centered on research areas related to the disciplines of history and archaeology. It might be worth noticing however, that while there are a small number of publications, more than half of the documents that are presented in this chapter have been published 2019 or later. This means that one perhaps can sense the building of a small momentum, where a marginal but nevertheless increasing amount of attention is being diverted towards the method of sonification within the digital humanities.

3.1 Sonification projects in the digital humanities

As it appears, sonification has mainly tended to attract attention among scholars working with the study of historical time within history and archaeology. This is perhaps not surprising given that sound is an intrinsically temporal medium. For instance, Graham (2016), citing Last and Usyskin (2015), argues that the sequential and time-based nature of sonification makes it especially suited for representing time-series data, and therefore also for the representation of historical progressions of time. A similar approach can be found in a master thesis by Wood (2019), in which the environmental and societal history of the Ottawa River is sonified in various ways. However, in most cases, sonification is not used for the representation of chronological data, but rather as an approach for engaging with historical artifacts in new ways. For instance, in two projects (Emsley et al., 2019; Emsley & Roure, 2016), the works of Shakespeare are approached through the use of sonification strategies. In another example (Wernimont, 2021), sonic abstraction is employed in approaching the sensitive subject of forced sterilizations carried out in the United States during the first half of the 20th century. Graham et al. (2020) provide a final example in which the locations of archaeological findings on an excavation site are remediated into musical sound.

In all of these cases, specific data sets have been prepared beforehand to serve as the raw material for the actual sonification. A more direct, unmediated and perhaps speculative method is explored by Kramer (2018, 2021) as well as by Graham and Simons (2021). This method, which they name digital image sonification, involves the direct remediation of the raw data of digitized historical photographs into sound. According to Kramer (2021), the combination of sound and image created this way has the potential of generating a new kind of media artifact, opening up for "new synesthetic modes of analysis" (M. J. Kramer & Noël, 2020, para. 5): "…oscillating between sight and sound, the visual and the auditory, seeing and hearing by way of computational tactics that transpose data from one form to another and between one human sense and another."

Apart from the sonification of images and data sets, there are further examples of digital humanities projects where sonification is used in relation to public space, as an experimental method for altering or deepening the experience of cultural heritage sites, landscapes, or public art. In the *DataScapes Project* (Bonnett et al., 2021), sonification is used in conjunction with Augmented Reality (AR) objects placed within a landscape. The purpose of the project is to explore how multimodal digital technology and AR can be used as "constituents of Landscape Architecture". In another project, *Soundmarks* (Ferraby & St John, 2020), there is once again a connection to archaeology. Here, the basis for the capturing of sound is the practices and tools used by archaeologists during the excavation of an ancient Roman town in Aldborough, England. The resulting sound works are meant to capture the characteristics of the sites, and are used as part of an interactive trail in which visitors are invited to explore the location in new ways and with fresh eyes and ears. In both these projects, there is a pronounced affinity to various art practices, more specifically to sound art and data art, moving beyond sonification as simply a scientific or practical method for conveying information.

Despite the fact that a multitude of very diverse sonification designs are used for these projects, one can also discern a few recurring patterns. Mostly, the designs are dependent on existing sound synthesis and sonification tools into which the data is fed. Examples of such tools are the Sonification Sandbox, developed at the University of Georgia, which is used by Wernimont (2021), the PhotoSounder, used by Kramer (2018, 2021), and TwoTone, utilized by Graham et al. (2020). In some cases however, code is implemented for exploratory examination of the data. One example of this involves the use of the Sonic Pi live audio coding environment, as demonstrated by Graham (2016). According to Graham, the use of such an environment has the benefit of making possible more control over the exact ways in which data is remediated into sound. It allows for a deeper awareness of the choices made along the way, granting the designer an independence from the predesigned affordances of existing software and thus allowing for more transparency regarding how the data is represented.

As for how these various sonifications actually *sound*, Kramer's (2018, 2021) remediation of digital photographs probably represent the most daring approach. In these rather experimental works, Kramer avoids the easily recognizable qualities and attributes that most people would associate with music. Instead, the pixels of the photos are correlated to frequencies of pink noise, where darker shades generate lower pitches, and brighter areas result in higher ones. The result – which can perhaps be described as rather harsh washes of pure noise – is described by Kramer as the "sonic x-rays" of photos (p. 6). However, most sonification designs referenced in this chapter opt for a more musical approach, using not only less abrasive timbres, but also recognizable tonal pitches and familiar scales (minor/major or chromatic). In some cases, discernible rhythmic patterns are also used. Such patterns are utilized by Wood (2019), where the seasonal changes of the Ottawa River are meant to be captured by a repetitive structure at the center of the sonification "song". The "musical" approach to sonification is otherwise perhaps best exemplified by the DataScapes project (Bonnett et al., 2021). Here, every letter in a text chosen specifically for the project was converted into a pitch in a musical scale. This material was then used as the basis for the work of two composers, who took active part in the molding of the sonic material by inscribing chords and altering the duration of the individual tones.

3.2 Epistemologies of digital humanities' sonifications

As can be seen, the projects surveyed in this chapter are quite diverse in nature. However, with regards to theory, many of them share a set of views on the epistemological potentials inherent in the use of sonification as a mode of data perceptualization. In a minority of cases, sonification is used in a predominantly utilitarian way, for instance by sonifying various editions of Hamlet in order to be able to spot differences between them without having to go through them word by word (Emsley & Roure, 2016). In one case, Wernimont (2021; Vibrant Lives, 2016) gives a rather original reason for the conversion of data into sound, arguing that sonic abstraction will function as a way of protecting the privacy of vulnerable people present in the data set. But mostly, a more elaborate rationale for the use of sonification is laid out. A recurring theme problematizes the dominance of data visualization and of visual modes for the presentation of knowledge within the (digital) humanities. According to Graham (2016, para. 3), we have become so accustomed to using visual representations that it almost makes us forget "...the artistic and performative aspect of those grammars of expression." That is, visualizations are never simple presentations of underlying data, but always interpretations. For Graham, sonification becomes a means for going against the grain here, making possible the questioning of certain presuppositions that underpin visualization as the dominant form of data perceptualization.

Related to this line of reasoning are a number of epistemological assumptions made about the affordances of sound and listening as a representational device in humanistic research. Wood (2019, p. 8) argues that we live in a world where "the primacy of sight is deeply entrenched", and that the visual tend to make claims of "objectivity and truth". As a way of counteracting this, Wood suggests that the act of listening to – rather than looking at – information might allow for a sensory and affective experience, making possible a more direct relation to it, perhaps also letting us confront that which is *other* in data. Graham and Simons (2021) also see potential in these affective dimensions of the sonic medium. Sonification, they suggest, should not aim at extracting quantifiable data, but rather at creating a sense of "enchantment", useful in historical research since it pushes for "a fuller, richer engagement with the past" (p.3).

A similar line of thought is explored and elaborated by Michael Kramer. However, Kramer does not focus on the isolated medium of sound by itself, but rather, as we have seen above, on the combination of sonic and visual modalities. He calls this approach AudioVisual Digital Humanities (M. J. Kramer, 2021). Kramer employs the concept of data fusion, originally developed by Lev Manovich, as a way of theorizing this combinatory method. Manovich defines data fusion as "*using data from different sources to create new knowledge* that is not explicitly contained in any of them" (italics in original). This approach does not only create a new object of study, but can also "give additional meanings to each of the sources" (Manovich, 2014, p. 339). For Kramer, data fusion becomes a strategy of *defamiliarization*, whereby the original material or data can be experienced in new ways (M. J. Kramer, 2021). However, the goal is not to approximate a more true image or representation, but rather "to play with the many representations of the artifact that become possible." (M. J. Kramer & Noël, 2020, para. 2)

A further way of constructing a rationale for the use of sonification can be found in the concept of *deformance*, utilized as a key theoretical approach not only by Kramer (2018, 2021), but also by Wood (2019) and Graham (2016; Graham & Simons, 2021). The term, a portmanteau word of "deform" and "performance", denotes "strategic acts of altering a text [to] produce new versions with revealing differences to the original" (M. J. Kramer, 2021, para. 3). It involves the intentional misreading of a text, for instance the reading of a poem backwards or the turning of a map upside down. But, according to Kramer, it also hints at something more fundamental intrinsic to the practice of digital humanities: that the concept of "raw data" is an oxymoron. As soon as data is remediated and represented ("performed") in some form, Kramer argues, it is always already deformed, intrinsically containing a range of possible perspectives (there is a clear affinity of this position with Johanna Drucker's insistence that all data should be understood as capta, something which is dealt with in the upcoming chapter on theory). Deformance, here achieved through sonification, can thus be understood as a method for making visible the constructed nature of data and of its representations. Sonification is perceived as a way to afford the act of analysis and interpretation with depth and reflection, at least when combined with other sensory modalities. According to Kramer (2021, para. 3): "We can listen more deeply to what we are seeing."

3.3 Theoretical limitations of existing research

The surveyed research, while peripheral within the field of digital humanities, testifies to the presence of a range of different approaches to the theories and methods of sonification. At the same time, the approaches tend to lack a certain depth and theoretical rigor. Often, the literature simply assumes, without thorough discussion, that the use of sonification or of sound comes with certain affordances. For instance, one recurring assumption is that sonification, in and by itself, makes it possible to avoid the claims to objectivity often inherent in data visualization. Another, expressed by for instance Wood (2019) and Graham and Simons (2021), involves a strong emphasis on the affective and "enchanting" qualities of sound and sonification. These assumptions are not necessarily wrong or unfounded. However, they are in need of a more rigorous theoretical development. Otherwise, among other things, one would risk too easily buying into an old and romantic understanding of the medium of sound, according to which sound and music allow for a more direct sensual communication than visual or textual modes of presentation (Straebel, 2010). This would most likely not make it easier to promote sonification as a plausible method for data perceptualization, in general or specifically within the digital humanities.

Perhaps part of the problem stems from the lack of any sustained engagement from the perspective of the (digital) humanities with the field of sonification. In the literature surveyed in this chapter, there are only brief and scattered references to existing, non-humanities theories and practices of auditory display and sonification. This means that the sonification practices that do exist within the (digital) humanities have hardly tapped into the knowledge base that is available through the contemporary field of sonification, which, as we have seen, has a history that stretches several decades back. Without seriously engaging with this history, one risks having to constantly reinvent the wheel. Part of what is needed is perhaps a (digital) humanities counterpart to the work done by Alexandra Supper (2012a, 2015, 2016, 2012b), in which the field of sonification is surveyed through specific theoretical lenses drawn from the qualitative social sciences. In the present thesis, something similar is therefore aimed at: by applying the critical hermeneutics of Johanna Drucker on the literature of sonification, the hope is to offer potential and future digital humanities sonification projects with more stable theoretical foundations.

4 Theory: The Critical Hermeneutics of Johanna Drucker

As was argued in the opening paragraphs of this thesis, the study of data through perceptualization, most often using tools and techniques for visualization, can be seen as an important and recurring concern within the digital humanities. At the same time, the use of existing data perceptualization methods has drawn criticism from scholars within the field. One important focal point for this criticism is that these methods and tools have been developed in the context of disciplines outside of the humanities, originating from fields such as business, statistics, and the natural sciences (see for instance K. L. Ferguson, 2019; Posner, 2016; Rawson & Muñoz, 2019). According to Masson (2017, p. 25), the work done in these empirical disciplines are, in general, epistemologically foreign to much research carried out in the humanities. One of the main reasons for this is that they aim at "measuring or testing observable phenomena in order to conclusively demonstrate tendencies or relations between them". In contrast, if some generalization is allowed, humanistic scholars do not take the "unassailable, objective truths" implied by such an approach for granted, choosing instead to confront their objects of study using methods that are of a critical and interpretative nature. According to Masson, given that tools and methods are imported in this way, the digital humanities can be seen as a space where different epistemic traditions come into contact with each other. The result becomes a process of negotiation, where the humanities becomes "increasingly indebted to positivist traditions".

Most of these critiques focus on data visualization. Sonification, as we have seen, remains a very peripheral phenomenon within the digital humanities. However, while there hardly exists a set of standardized and easily accessible tools for sonification – something which is often available for data visualization – even a brief overview of the field will make clear that most sonification projects deal with data and areas of research derived from the empirical and natural sciences. This means that if sonification is to be suggested as a method for the digital humanities, the critical approaches mentioned above need to be explored and repurposed in relation to sonification as well. In this thesis, this will be achieved by applying the critical theory of Johanna Drucker on existing practices of sonification. Drucker is one of the digital humanities scholars who is often associated with a critical approach towards data visualization, and she has been reiterating and developing her critique in a number of different contexts and publications (see for instance Drucker, 2011, 2016; Drucker & Bishop, 2019). However, in this thesis, the description of Drucker's various positions will mainly be drawn from the book *Visualization and Interpretation: humanistic approaches to display* (Drucker, 2020). In this book, Drucker applies critical theory and hermeneutics on tools and methods for visualization used within the digital humanities, formulating a theoretical framework based on a constructivist epistemology. Given that the following chapter will mostly be based on this book, all references, if not otherwise stated, are drawn from it.

4.1 Central ideas

At the core of Drucker's critique can be found the assumption that (digital) research tools can never be considered neutral. Instead, they tend to reflect and therefore also reify the epistemological perspectives common to the disciplines within which they have been developed. As a consequence, all digital research tools are not equally well suited for all types of research. For instance, visualization software developed for the statistical sciences cannot simply be repurposed for the humanities. This is because the type of research objects that are common within the humanities (e.g., a novel, a historical document, a philosophical idea) demand a specific set of methodological approaches, radically different from the ones applied within the "hard" sciences. According to Clement (2016), these approaches are grounded in interpretation and hermeneutics; approaches that constitute the underlying, but often unexamined, method of the humanities. Drucker comes to the same conclusion. While she acknowledges that the humanities are by no means a "unified monolith" (p. 63), she nevertheless argues that interpretative perspectives are central to many, if not most, humanistic research practices. For the humanist, ambiguities and a multitude of possible perspectives and modes of interpretation are generally not characteristics that can be done away with through more efficient methods. Rather, they are unavoidable and, furthermore, desirable. The task is therefore to develop methods and tools capable of reflecting this nature of humanist research.

Digital tools for visualization used within the digital humanities make possible the creation of artifacts such as timelines, charts, graphs, maps, and diagrams. The problem is that the tools are not suitable for the type of interpretative work described above. Or, rather, one type of interpretative work is already coded into the algorithms and protocols of the tools, and is thus performed accordingly, sealed off from direct engagement by the researcher. The interpretative framework becomes hidden (Drucker, 2011). Mentioning one example out of many discussed by Drucker, it is common that tools make use of graphical means that are "characterized by discrete components and disambiguated features" (p. 112), which reflect quantitative approaches. According to Drucker, visualizations produced this way tend to be declarative in nature, stating interpretation as fact. They are part of a "representational paradigm" in which "the relation between data and display is unidirectional, the data precedes the display, and the data is presumed to have some reliable representational relation to the phenomena from which it has been abstracted" (p.76). The alternative to this mode of thinking – according to a well-known suggestion by Drucker – is to reconceive *data* as *capta*. The term *capta* is meant to capture the fact that no data, according to Drucker, "pre-exist their parameterization" (Drucker, 2011, para. 8). That is, the collection or extraction of data always involves an act of interpreting the phenomenal world. This means that data is not "given", as the etymological roots of the word "data" would suggest (from the Latin *dare*, meaning *to give*). Rather, it is the result of an active intervention: it is "captured", therefore "capta".

The distinction between data and capta points to another crucial tenet of Drucker's critique: that there is a need for radically new conventions for data perceptualization, based on a new understanding of what data is and can be. While she remains suspicious of most existing methods for visualization and data representation, she does not exclude the use of such tools within the (digital) humanities *per se*. Quite the opposite, Drucker sees potential in non-textual modes of knowledge production. For one thing, she notices that there has been a long-standing distrust against visual expression as a stand-alone form of knowledge within the humanities in western culture. Therefore, the application of novel conventions on non-textual and visual forms has the capacity to push against a set of existing prejudices, making possible new lines of thought and inquiry (p. 10). Here, Drucker underlines that the (fine) arts have an important role to play. Knowledge drawn from aesthetics and from the aesthetic imagination has the capacity to overcome the "impoverished methods" that characterize dominant approaches to visualization. She for instance states that "[t]he sophisticated capacities of eye and image need to be put in the service of knowledge and models of interpretation." (p. 68) In the context of this thesis, one could perhaps also suggest the same of the ear and of sound.

While Drucker notices that the kind of critical approaches she advocates are quite common within digital humanities projects, they are often only applied to the *content*, not to the *method* of these projects. According to Drucker, there therefore exists a need to shift from critique and redesign to design. Put succinctly, the challenge consists of how to create computational tools and methods that support interpretative work typical to the humanities. Such tools should not, using Drucker's vocabulary, aim at *visualizing information*, but at *modeling interpretation*. In this context, the term *modeling* should not be confused with 3D rendering software, but is to be understood as "the process of creating a generalized intellectual schema or structure" (p. 76).

Drucker describes the difference between information visualization and modeling interpretation as reflecting the difference between realist and constructivist epistemologies. The methods created should therefore embody such constructivist perspective. First and foremost, they must clearly bring to the forefront the constructed nature of data, exposing it as capta. This should be achieved by making the whole life cycle of data production transparent, all the way from data collection or extraction, through parameterization, quantification, sampling, etc., to display or perceptualization. By making visible the decisions shaping the data on which a particular visualization – or any form of perceptualization – is based, the modeled nature of information is brought into view. The idea is that this way the end result will become less assertive and declarative. For Drucker, the idea is to create more of a "what if" than a "this is" kind of statement (p. 56), thus making possible a wider range of interpretative approaches.

This preference for "what if" statements brings to the fore another important aspect of Drucker's constructivist epistemology: that interpretation should be viewed as a probabilistic practice. Here, Drucker draws on 20th century hermeneutic philosophies, insisting that no text is capable of transferring meaning "in a mechanistic way" (p. 44). Instead, each act of reading involves a process of negotiation between text and reader. This means that the knowledge, experiences, and lifeworld of the physically and culturally situated reader need to be taken into account. Here it is important to note that the words “text” and “reading” do not only refer to the study of textual modes of presentation. As is common within the epistemological tradition to which Drucker belongs, a “text” is understood as a much wider concept which can be found within all types of modalities. For example, an image or a combination of sounds can constitute a kind of text. This view of the practice of interpretation creates an epistemology which suggests that the range of potential readings “creates a field of possibilities” in which “every act of reading is an intervention in that field” (p. 45). Once again, since no single point of view is possible, the production of ambiguities and contradictions should be viewed as an unavoidable component of the practice of reading, something that also should be modeled in the tools used.

Ultimately, Drucker’s critique revolves around the fact that it is not only the objects of research that set the humanities apart from the natural and empirical sciences, but also, and perhaps more importantly, the very objectives of the research itself, and, consequently, the end result which this research is expected to yield. Among other things, this can be said to reflect divergent views on what constitutes knowledge, and on how this knowledge relates to the objects of research. Within many humanities disciplines, the production of knowledge seldom means finding conclusive evidence proving a specific hypothesis or perspective. Instead, when researching the cultural record of human societies – the overarching object of study of the humanities – the aim is generally not to shed, but to highlight and bring to the fore its aspects of ambiguity, uncertainty, nuance, and complexity. For this reason, when designing tools, Drucker warns against being too dependent on methods drawn from Human-Computer Interaction (HCI). While not denying that the field provides useful insights for the digital humanities, Drucker nevertheless argues that HCI is characterized by a “mechanistic pragmatism” (p. 97). The design of tools within this paradigm tends to embrace a utilitarian perspective, where the goal is to complete and progressively move on from a specific set of discrete tasks. In contrast, Drucker argues that the digital humanities should embrace a radically different view, designing tools for which “[s]ustained interpretative engagement, not efficient completion of tasks, would be the desired outcome.” (p. 133)

4.2 For new methods of data perceptualization

So, what should digital tools that allow and aim for such “sustained interpretative engagement” look like? As we have seen, a critical perspective on existing tools and methods is commonplace among digital humanities scholars. The critique often comes coupled with calls for the development of new and humanities-specific digital tools. One example of this is Ferguson (2019, para. 3), who advocates an “investment in experimental, theoretical methods that run counter to the rationalist uses of quantitative data often employed in DH work”. However, according to Drucker, suggestions on how to design these tools and methods are often left to future occasions. As we saw above, Drucker argues that the critique often only belong to the *content* of digital humanities research, without actually making any deeper impact on its *methods*. Thus, while many existing critical approaches might highlight the need to be wary of results achieved when using tools borrowed from the empirical sciences, they do not offer ways of doing away with the dependence on these tools. In these cases, the critique is insufficient.

In the closing sections of her book – as a consequence of her own line of argumentation – Drucker puts forward a set of design proposals, meant to function as practical suggestions for remedying the situation. The proposals are concrete to a varying degree. In some cases, the designs describe tools that have been developed within the contexts of actual existing digital humanities projects. While the designs in these cases are not necessarily completely finished, they at least describe a concrete set of suggestions. In other cases, the designs are purely speculative in nature, spelling out suggestions on how to tackle existing challenges when developing tools within the digital humanities. The overarching aim of all these design proposals is to explore alternatives to conventional visualization strategies and to the assumptions underpinning them. Thereby, Drucker hopes, a contribution towards the creation of new conventions is offered. Importantly, these new conventions should make readable aspects of interpretation such as contradiction, ambiguity, and comparison. Further, given that Drucker rejects the idea that data can be seen as a neutral raw material for visualizations; interpretation should not be generated by structured data and metrics. Instead, the visualization should itself generate these things. Finally, innovative humanistic approaches should draw inspiration from the fine arts and design fields.

Many of these design suggestions and outlines are not relevant in the context of the present thesis. One reason for this is that not all aspects of Drucker's multifaceted critique can be taken into account in a thesis of the present scope. However, a more important reason has to do with the nature of sound itself. Abstract, non-speech sound comes with very different affordances when compared with the visual and textual modalities discussed by Drucker. These differences need to be taken into account if aspects of Drucker's theory are to be implemented in the context of sonification (which is perhaps the main purpose behind the extended literature review that makes up the sixth chapter of this thesis). For instance, Drucker's discussions on alternative methods for visualizations of maps and spacial information (p. 120) are of lesser importance when dealing with sonification design (not excluding, of course, that they might serve as inspiration for some clever sonification design). One very important difference is derived from the fact that sound is an inherently temporal medium. Sound cannot, in the same manner as information visualization and graphical forms of display, present a complete set of information in an instantaneous manner. Instead, it evolves over time and reveals its material gradually. On the surface at least, this means that with data visualization, a user can choose to follow many different interpretative paths, while with sonification, one is constrained to one specific path, following the development of the sounds. In any case, the temporal nature of sound means that, in this thesis, special attention is given to Drucker's discussions on the modeling of time and of temporality.

According to Drucker, the timeline is the most common and conventional form for visualizing time. In general, a timeline presents the passage of time as a linear movement through a visual space that is evenly divided and marked in accordance with one or several standardized units of time (seconds, days, years, etc). Drucker argues that this is a convention that functions as a restraint in relation to many types of (digital) humanities research, and she describes two overarching problems. First, conventional timelines visualize time in a mathematical manner, assuming it as a phenomenon that is “unidirectional, homogeneous, and continuous” (p. 114). While this might work well within the natural sciences, it generally does not reflect the way in which time is experienced by human beings in everyday life. As a consequence, Drucker argues, timelines fail to take into account the complexities of how lived time is reported and produced in collections of documents. Such documents often contain narratives expressing a situated experience of time, a common object of study within the humanities. As an example, Drucker discusses the (fictional) novel. In a story, Drucker argues, time does not flow steadily forward, and it is not marked by a set of standard units. Instead, scale changes constantly, and time is presented through broken chronologies, through anticipation and flashbacks: “The story is told in segments, chunks, with gaps and breaks” (p. 115). Temporality works in a similar manner in non-fictional narratives, describing non-fictional events (e.g., a subjective description of an historical event).

A second, and somewhat related, problem with conventional timelines is their inability to make visible multiple – often contrasting or even directly contradictory – chronologies. According to Drucker, attempts at making sense of the culture of human history have produced a range of different chronological schemes. In some cases, different schemes “overlap, coordinate, intersect” (p. 117) and can therefore be correlated or reconciled. In other cases, such correlations are not possible, and the chronologies cannot be forced into a unified timescale. One common reason for this is that the schemes have been produced within the context of different temporal and/or cultural spheres.

As a response to these problems, Drucker outlines a set of design proposals that take aim at creating *interpretative* and *heterochronological* timelines. Rather than simply representing time, such timelines attempt to model temporality in a manner that is “multidirectional, discontinuous, and nonhomogeneous” (p. 114). While not excluding the use of time-stamped information or standard metrics *per se*, their main aim is to focus attention on the relational features of temporality. For instance, events on an interpretative timeline are not presented as discrete units, but as codependent with and influenced by other events, points or periods in time. Drucker points out that the constitution of an event – its duration and the exact dates on which it begins and ends – seldom can be seen as clear-cut, completely without ambiguity. This needs to be made visible in the graphic conventions used for its interpretation. Given that an event needs to be delimited from many different angles, the conventions should also allow for many parallel timelines, which makes possible the interpretative encircling of events, while preserving the inherent ambiguity of these events.

These discussions regarding timelines reflect a larger concern for Drucker. This concern is not only visible throughout most of her design proposals, but is also of crucial importance to her theoretical project as a whole. It involves a need to create conventions for visualization that preserve the inherent richness and complexity of many humanities research fields and objects of study. Rather than hiding these aspects of the research behind layers of comfortable interfaces and code, the tools created need to bring them to the fore. The challenges involved when creating such tools are discussed in a section dedicated to the design of tools for “rich (discursive) research fields” (p. 124). These types of research fields make extensive use of the complex combination of discourse found in collections of documents. Such collections make possible multiple, or even infinite, ways in which they can be “used, connected, analyzed, and interpreted”. This means that the system to be designed needs to be “capable of holding many arguments made from the same evidence” (p. 125). Drucker makes an analogy to the drawing of constellations on a map of stars: one could imagine and draw an almost endless variety of constellations. Nevertheless, constellations are dependent on the actual layout of stars in the sky. Each line represents a potential interpretative path through the same material. In the same way, tools developed for rich research fields would need to have “the capacity to maintain and preserve alternate (infinite) readings of the evidence”. The “lifecycle or at least partial history of the development of the argument” would also need to be visible (p. 127).

The design suggestions aimed at tackling the challenges of rich research fields exclusively utilize visual modalities. They also make extensive use of text-based components and solutions through annotations and through the direct presentation of written arguments. Nevertheless, a number of the challenges described in the section will be relevant for any attempt at perceptualizing humanities data, no matter the medium used. For instance, such perceptualizations will need to make possible the display of many different interpretative paths through a given set of evidence. They must also avoid the convenient reduction of ambiguities and complexities in a material. With this in mind, an overarching aim of this thesis is to explore the potential of sound and sonification for preserving and highlighting the richness and complexities inherent in many humanities sets of data, especially in relation to the temporal nature of the sonic medium. This means that special focus will be directed at time-series data and on the capacity of sonification for modeling temporality, in the sense theorized by Drucker.

Finally, a few comments need to be made with regards to the use of interactivity within the designs suggested by Drucker. On a general level, Drucker is wary of the manner in which interactivity is implemented in many conventional tools for data visualization. Often, she argues, these implementations only grant users an illusion of control while the system, through design choices made “under the hood”, in actuality steer them in an already defined direction. Nevertheless, Drucker imbues interactivity with a certain degree of potential. For instance, the adding of interactive elements to humanistic visualization designs holds the potential of multiplying available points-of-view, and thereby de-naturalizing claims of a universally valid presentation. Interactivity can for example be very useful when dealing with the multiple and partially overlapping chronologies or timelines discussed above, given that it allows the scholar-user to actively shift between them. It seems reasonable to assume that interactivity holds similar potentials in all forms of data perceptualization, and that it can be a useful component within the context of sonification systems. However, the invention and design of interactive systems also add many additional layers of complexity, as compared with purely sound-based systems. Therefore, as is discussed under delimitations in the chapter on methodology below, while interactivity is not ignored, it is largely deemed outside the scope of this thesis, and it will not be explored in any depth.

4.3 On the definition of "humanities data"

Given that one of the main aims of this thesis is to explore sonification as a method for perceptualizing data within the humanities, the concept of *humanities data* needs to be clearly defined. Following Posner (2015), one can argue that the term humanities data is both necessary and self-contradictory. Necessary, given the increasing amount of data produced within humanities disciplines; contradictory, since there is no "data research" in the humanities comparable to the type of quantitative data research conducted in non-humanities disciplines. Regarding the question of definition, one perhaps has to relate it to the more general issue of how to define the digital humanities as such. According to Fitzpatrick (2011), there are two overarching conceptions of the nexus of fields that comprise the digital humanities. One understands the digital humanities as the study of traditional humanities subjects through the use of computational technologies. The other – and much broader – view suggests that digital humanities should also include the application of interpretative humanist methodologies to computing and to "the digital". If one accepts the latter view, any data, regardless of its origin, could potentially be considered the object of study for a humanities-oriented inquiry, and thereby be considered humanities data. In a similar vein, attempts at defining the more specific concept of humanities data have made use of very broad criteria. For instance, Borgman argues that "[a]ny record of human experience can be a data source to a humanities scholar" (Borgman, 2009, para. 33). A more thoroughgoing and delimited definition is provided by Schöch, who suggests that it is "a digital, selectively constructed, machine-actionable abstraction representing some aspects of a given object of humanistic inquiry" (Schöch, 2013, para. 6). For the purpose of this thesis, this very useful definition of humanities data is further supplemented as including only *data that has been produced within the context of humanities scholarship, and/or that covers traditional objects of study within the humanities*.

This does not mean that data derived from non-humanities fields or disciplines cannot be subjected to humanistic modes of inquiry. Quite the opposite – as we will see as the thesis progresses – there exist a range of examples of non-humanities data being sonified in manners relevant for the (digital) humanities. However, this does not necessarily turn this data into "humanities data". Further, the concept of "data" in humanities contexts should always be used with critical caution. This is after all one of the reasons why Drucker suggests replacing the term "data" with "capta". Nevertheless, the term "data" will be used in combination with "humanities" throughout this thesis. One of the more important reasons for this – apart from the fact that "data" is the conventional term, regardless of its shortcomings – is that it facilitates learning from data-based work done in disciplines and fields outside of the humanities. Put differently, as is argued in Arnold and Tilton (2019), perhaps the sharing of terminology might make it easier to find common ground between disciplines, avoiding having to reinvent the wheel when there is no actual need to.

This is also one of the key aims of this thesis: to ground the sonification of humanities data on findings drawn from non-humanities sonification practices that often base designs on natural-scientific data.

5 Methodology

The overarching methodological structure of the thesis can roughly be subdivided into two main parts: one theoretical and one practical. The first part consists of an extended literature review, while the second part is made up of a description of an exploratory sonification design. Leading up to the conclusion of the thesis, the second part also includes a brief user study, in which the final sonification design is evaluated through the feedback provided.

5.1 Purpose and aims

The overall objective of this thesis is to provide a preliminary exploration of sonification as a method for perceptualizing data within the digital humanities, aiming at expanding available means for engaging with large-scale humanities data sets. This will involve the use of both theoretical and practical perspectives. Theoretically, the thesis will aim at aligning existing practices of sonification with critical approaches to data representation found within the digital humanities, as represented by the critical hermeneutics of Johanna Drucker. The resulting perspective will then be put into practice through the design of an exploratory sonification, in which a large-scale musical data set will be remediated into sound. The purpose is to put forward an early design prototype that can inform and inspire potential future humanities sonification projects.

This yields the following research questions:

What existing theoretical and methodological perspectives within the field of sonification can be applied when dealing with humanities data?

How can these perspectives be adapted to the critical approaches to data perceptualization and representation found within the digital humanities, as expressed by Johanna Drucker?

In what ways can the use of sonification enrich the interpretative possibilities when exploring humanities data, here represented by a large-scale musical-historical data set?

5.2 Extended literature review

In the extended literature review, a range of publications on sonification are discussed and put into relation with the theoretical framework of the thesis. The fundamental assumption underpinning the review is that the challenges involved in dealing with data perceptualization within the (digital) humanities are not necessarily unique. Digital humanists should perhaps especially keep an eye on work being done within the qualitative social sciences (Clement, 2016), but could also benefit from experiences drawn from other fields, including the (natural) sciences. Put succinctly, the idea is that the extended literature review will make a contribution that will diminish the need for reinventing the wheel when it comes to sonification.

The focus of the extended literature review is directed at three overall areas: 1) theories on the affordances of sound and hearing, and on the epistemologies of sonification; 2) design methodologies; 3) practical examples of sonification projects that can be aligned with – or that make use of – (humanistic) interpretative methods.

The material for the review is comprised of books, articles, papers and theses retrieved during March and April 2022. As we saw in the Background chapter, the International Conference on Auditory Display (ICAD) can be seen as the most important center of gravity for the sonification and auditory display community (G. Kramer & Walker, 2005). Therefore, the ICAD Proceedings (Georgia Tech Library, n.d.) have received special attention in the thesis, and all the included papers published 1994–2019 – the complete set published at the time of writing – have been surveyed for the review. Further, searches were conducted using the Linnaeus University Library OneSearch discovery system (focusing on the search terms: sonification OR audification OR "auditory display") (databases available through the OneSearch system can be found in Appendix 1). The decision to include all databases covered by the OneSearch system – rather than searching in a limited and more specific set of subject databases – was partly based on the fact that sonification is a multi- and inter-disciplinary field, and that publications therefore are indexed by a range of different subject databases. Apart from this, when conducting early exploratory searches, a relatively small number of publications were recalled. A broad and inclusive search strategy was therefore deemed to be the most effective, even if this meant sacrificing a certain degree of transparency and reproducibility. Finally, publications referenced within the literature were also added when considered relevant, and Google Scholar was used in order to better cover "gray literature" (i.e., theses).

Regarding the scope and ambition of the review, it must be made clear – as an important preliminary delimitation for the thesis – that it has not been conducted with any pretense of being exhaustive in relation to all the literature on sonification. While the selected material has been surveyed in a systematic manner, it does in no way present the entire material systematically. Instead, the review is exploratory and heuristic in nature. It follows a few lines of thought running through the literature with the purpose of theory construction. The aim of the review is to present an original theoretical contribution to the practice of sonification and to the digital humanities, sketching a preliminary model for the use of sonification in (humanistic) interpretative work. Beyond that, its purpose is also to inform the sonification design that makes up the second part of the thesis.

5.3 Sonification design and user study

The process of sonification design and evaluation involves sonifying the "Spotify 1921–2020" data set using the SuperCollider audio programming language (described in chapter 7.1 and 7.2, respectively). The purpose here is not to create a finished tool. Instead, the design process will involve what Montfort (2016a, 2016b) describes as exploratory programming. This type of programming is not aimed at producing the deliverables typical of software engineering, but can rather be seen as a method to "think with computation" (Montfort, 2016a, p. 3); it is "a process that enables the programmer to discover, in the process of programming, the ultimate direction the project will take" (p. 1). Through exploratory programming, the inherent possibilities and challenges involved when sonifying a humanities data set will be probed. Notwithstanding the exploratory method, the goal is to create an end result in the form of a demonstrable sonic representation of the data set.

The sonification should be considered an early prototype. It should also be seen as part of the larger, overarching argument put forward in the thesis, building on the findings in the extended literature review. Nevertheless, any sonification design – including ones that are considered early prototypes – should have some form of possible (future) usage in mind. Therefore, a small user study is conducted. Given the nature of the data set, the survey was designed for a specific group of people for which a certain degree of prior knowledge regarding the nexus of music and technology could be assumed. With this in mind, the respondents were recruited through two channels: through a post in the SuperCollider group on Facebook (SuperCollider, n.d.) and through an invitation sent out using a mailing list for academics working in an interdisciplinary manner with aspects of music, musicology, and technology.

As for the form of the user study, it is qualitative in nature and is conducted through the use of a short questionnaire, made available through Google Forms. The questionnaire is of an open-ended nature, asking the respondents to provide written answers of any preferred length. In eight brief questions, it asks the respondents to describe their subjective interpretation of the sonification and its contents (see Appendix 2 for the full information provided to respondents). Given the prototype nature of the sonification, techniques for constructing the survey have drawn on a short review by Brazil and Fernström (2009), which deals with methods for capturing subjective experiences of early conceptual designs for auditory display. Brazil and Fernström argue that by surveying and taking into account such early experiences, it becomes possible to involve the intended users in many of the stages of the design process, thereby designing *with* rather than simply *for* these users. It further facilitates in "determining users' needs and desires as well answering questions like what a person thinks of when they hear a sound or what sounds do they find confusing. [sic]" (p. 4) As has been made clear above, the sonification design developed for this thesis will not be moving beyond the stage of early conceptual design. Therefore, the suggestions of Brazil and Fernström are seen as particularly useful.

Regarding the content of the user study, it will not only consider how well the sonification is able to transmit various data dimensions, but also take into account its aesthetic dimensions. In their small study on aesthetic evaluations of sonification designs, Vogt et al. (2013) argue that it is necessary to better understand how aesthetic qualities influence the impact of sonifications for the method of sonification to reach a wider audience. Further, drawing on Drucker, it is one of the core arguments of this thesis that the aesthetic dimensions of data perceptualization – the *how* of what is being presented rather than simply *what* is being presented – cannot be seen as merely ephemeral, but fundamentally shape its content.

Finally, given that the user study makes use of a questionnaire directed at human subjects, a short note on ethics is warranted. Possible ethical issues that need to be taken into account relate to any potential of harm being done through the research – both to subjects and to researchers – to the ensuring confidentiality and to the establishment of informed consent (Eynon et al., 2017). Given the uncontroversial and rather abstract nature of the research – sonification prototype design – potential ethical issues are deemed to be negligible. Respondents participate on a voluntary basis, leaving anonymous replies through an online form. The replies are partially quoted throughout the text, but not supplied in full. Regarding informed consent, a thorough description of the research is provided (see Appendix 2) in order to ensure that respondents understand its nature and aims. If an ethical issue is to be identified, it relates to the use of major commercial and data-extracting platforms – Facebook and Google – for recruiting respondents and for collecting replies. As is often the case, they have been used because of reasons of time constraints and of convenience and – in the case of the SuperCollider group on Facebook – simply because it is the platform the community uses for communication.

5.4 Delimitation

Sonification makes data perceptualization possible without relying on the sense of vision, making it potentially valuable for visually impaired users. While this is true for any kind of sonification, there exists a specific area of sonification research that is dedicated to this subject. However, one of the more important propositions made in the thesis is that sonification has the potential of being useful for wide groups of users working within the (digital) humanities. Therefore, while auditory display for the visually impaired is an important area of research, it will not be dealt with in this thesis. Further, there is a long range of sonification projects that combine sound with visual and/or tactile modalities for perceptualization and interaction. These types of multimodal sonification are not the focus of this thesis, and the main reason for this is that they tend to add additional layers of complexity when compared with purely sound-based designs (which is discussed in de Campo, 2009). However, one has to work with what one finds. Therefore, when deemed relevant, in the extended literature review as well as in the chapter on previous research, a number of sonification examples involving visual elements, live performance by musicians, and even dance will be discussed. In these cases, focus will be directed at the sonic aspects of the designs in order to keep with the sound-oriented focus of the thesis.

While not wanting to adhere to one single definition of sonification, the term sonification as used in the thesis still needs to be delimited in relation to other types of sonic information transmission. In the thesis, sonification is therefore understood as a category of auditory display which aims at making audible the "inherently silent abstractions" of data (Worrall, 2019, pp. 23–25). Other types of auditory display include auditory icons, which can be described as a sound explicitly meant to represent a given object or action (e.g., the sound made when an object is moved to the trash can on a computer desktop), and audification, which involves the amplification or morphing of an already existing signal (e.g., the amplification of seismic signals). Compared with audification, it can be argued that sonification demands a more active and extensive intervention on behalf of the designer since there is no single or given way in which the data can be remediated. Discussions of these other types of auditory display will largely be avoided.

6 Extended Literature Review: The Field of Sonification and the Humanities

6.1 General characteristics of field

While a comprehensive survey of the field of sonification as it stands today is well beyond the scope of this thesis, it can nevertheless be helpful to introduce this chapter by presenting a summary of a few general findings. To begin with, it must be pointed out that sonification cannot be understood as a unified field of practice, but rather engages with and draws on a range of different disciplines. For instance, according to Worrall (2019, p. 23), the design of sonifications requires one to take into account "music composition, perceptual psychology, computer science, acoustics, biology and philosophy". Further, the data used as raw material for sonifications are also derived from many different disciplines and fields. Nevertheless, when surveying the literature – and especially the ICAD proceedings – a few general tendencies become clear. To begin with, sonification projects are mainly realized within and focused upon the natural sciences. This means that data and research questions are principally derived from disciplines such as physics, biology, astronomy, climate science, medicine, and meteorology. Therefore, the field of sonification has traditionally been dominated by natural-scientific epistemologies, and the designs consequently have made use of perspectives drawn from engineering. A rather typical view of data representation and of the tasks of sonification – at least during the early days of the field – can be found in an influential paper by Barrass (1994). According to the perspectives expressed by Barrass, it is imperative that designers of auditory displays and sonifications strive to preserve the underlying interrelationships between the data points, avoiding that interpretation is distorted or biased through processing artifacts. In other words, a true representation of data is presumed, and it is the goal of the designer to come as close to such a representation as possible.

These general characteristics of the field are corroborated by studies surveying the auditory display and sonification from a meta-perspective. For instance, Bearman and Brown (2012) argue that while there exist an abundance of sonification projects focused on for example biology and physics, little attention has been directed at sonification from within the social sciences. This, they point out, is perhaps somewhat surprising when taking into account that there is a long-standing quantitative tradition within the field. As for qualitative disciplines, they find that these are hardly represented at all. Supper (2012b) makes a similar observation, suggesting that sonification only rarely has been able to attract attention from the humanities and social sciences. However, in the same text, Supper also makes clear that the multi- and trans-disciplinary nature of the field means that it never has been monolithic, and that it remains divided with regards to the conception of "objectivity and scientific quality" (p. 32). There are also signs that the field is diversifying, and that it over time has come to incorporate a wider range of disciplines, including disciplines from within the humanities (Sterne & Akiyama, 2012; Supper, 2015). The digital humanities sonification projects surveyed in the chapter on Previous Research in this thesis might be a sign of this, but it is also evident when surveying titles and abstracts from the ICAD conferences. There are also tendencies toward a diversification of the epistemological underpinnings of sonifications, where new approaches striving to move beyond the "positivism" of the early days are becoming more widespread (Worrall, 2019). This will be discussed in the subchapter on the epistemologies of sound and listening below.

As has been pointed out, the natural sciences tend to dominate the field of sonification. However, there is one major and important exception: the involvement of the humanities disciplines of music and musicology. This is perhaps not surprising given that practitioners of both sonification and of music generally work with the structuring of "non-speech audio" and given that there is a well-established base of knowledge within the field of music on how to structure and make intelligible abstract sound. Tellingly, Neuhoff (2019) found that 70 percent of papers presented at ICAD mention the word music. While the use of sonification for the study of music is quite uncommon (however, there are exceptions, see for instance Ash, 2012; S. Ferguson & Cabrera, 2008; Kostek, 2013; Winters & Cumming, 2014), musical perspectives and practices often play an important role in sonification design. These practices and perspectives do not only include musical composition in the more traditional sense, but also make use of skills and experiences drawn from sound design and film music (Back & Des., 1996; Scubert et al., 2011; Somers, 2000), as well as from computer games (Barrass & Vickers, 2011). In these examples, sonification is thought of as a narrative process, in which sound is structured as a story, in accordance with what the sound designer wants to communicate. Such approaches can be seen as an alternative to the positivist epistemologies discussed above, as represented by Barrass (1994). In contrast to such epistemologies, narrative approaches to sonification seem to align with Drucker's (2020) contention that data perceptualization always involves the (more or less) conscious making of an argument. They also provide valuable insights into alternative methods of presenting and modeling time, when compared to standard and linear, timeline-like models of representation.

6.2 Sound, listener, and embodied cognition

Supper (2016) observes that a recurring idea within the sonification literature suggests that sound and the sonic realm are underprivileged in comparison with visual modes of expression and representation. According to many practitioners within the field, the use of sound for data perceptualization remains underexplored, signaling that the field is still in its infancy and thereby holding potential for future exploration. For instance, in one of the founding documents of sonification and auditory display as a field (G. Kramer et al., 1997, sec. 4.4), the academy and research community at large are described as "visually biased", which is why they tend to shun sonic modes of data perceptualization. Since there exist a long history of graphical representation of data – not least due to the fact that visualization methods and technologies have been around for a long time – the bias is partly explained by historical factors. But the bias is also understood to be a consequence of "the current prevalence of sophisticated digital graphics and data visualization techniques." Somers (2000) suggests that the visual bias has even deeper historical roots and argues that the eye – the sense of seeing – has been privileged over the ear and hearing in western culture. He also points out that when sound is used in combination with image, the medium of sound tends to take on an accompanying role, highlighting aspects of what is already present in visual form.

However, while the idea that sound is not used enough seems widespread in the literature, there exists no unified understanding of the potentials of sound for data perceptualization, no consensus regarding the affordances of sound for representing, exploring, or interpreting data. To survey all the ideas within the field on the affordances of sound in a complete manner is well beyond the scope of this thesis. However, these ideas – as an overall tendency – seem to be dependent on the underlying epistemological assumptions and convictions of the sonification designer. That is, a sonification designer with positivist convictions and aims might ascribe sound with the capability of transmitting information in an unambiguous and logically coherent manner, presenting a true representation of underlying data. For instance, in Barrass (1994), who, as we have seen, can serve as an example of the "engineering theories of information transmission" that was common in the sonification community during its early days (Barrass, 2012), sound is described as having the potential to increase "the communication bandwidth at the human-computer interface" (Barrass, 1994, p. 331). A similar view can be found in Bonet (2019), where the Shannon-Weaver mathematical theory of communication is applied to the sound of sonification. According to this rather strict theory, sonification means encoding information through sound in the form of a signal, which in turn is decoded by the person listening (the receiver).

Such perspectives on sonification as information transmission clearly have little to offer when regarded through the lens of Drucker's critical hermeneutics. Indeed, they can be seen as an expression of what Drucker describes as the representational paradigm, which posits a unidirectional relationship between data and display, and which presumes data "to have some reliable representational relation to the phenomena from which it has been abstracted" (Drucker, 2020, p. 76). Within the sonification community, an alternative to these representational perspectives is provided by the paradigm of *embodied cognition*. Theoretical approaches drawn from embodied cognition are quite common in more recent sonification literature, and are often presented as a conscious move away from positivist and engineering perspectives on sonification design (Diniz et al., 2010; Gossmann, 2010; Jeon et al., 2013; Roddy & Furlong, 2013, 2015; Supper, 2016; Tuuri & Eerola, 2012; Worrall, 2019). For instance, Roddy and Furlong (2013) argue that the potentials of auditory display long have been hampered by a "naive realism" which posits a direct access of the senses to the exterior world (p. 127). This naive realism has further been coupled with a cognitivist approach that assumes that the human mind intercepts and process auditory signals and symbols much like a computer – a view that according to Worrall (2019, p. 110) reflects a one-sided focus on thinking as "abstract reason". Combined, these paradigms fail to take into account how the interpretation of sonic symbols is a meaning-making activity, how "[a]ny attempt to understand human interaction with auditory phenomena will necessarily concern itself with meaning" (Roddy & Furlong, 2013, p. 128).

According to the approach of embodied cognition, this meaning does not appear out of nowhere, but is rooted in bodily experience. Roddy and Furlong (2013, p. 130) point out that “all mental activity, imaginative or rational, must arise from the states and activities of the body in which it is associated”, while Tuuri and Eerola (2012, pp. 138–139) state that “our cognition, including sound-meaning structures, is integrally coupled with an ongoing world and embodied experiences of interaction”. Put differently, “the embodied view sees cognition as the enactment of the world and mind” (Tuuri & Eerola, 2012, p. 138). In the context of auditory display and sonification, this means that the listener is no longer perceived as a passive receiver of informational content, who is simply decoding what is already fully present in the audio signal. Instead, the listener is understood as an active party that infuses the sonic symbols of sonification with meaning. On the one hand, this means that there is no pre-given meaning inherent in a particular sound by itself, and that different listeners will not necessarily recognize patterns in a particular sonification in similar ways (Gossmann, 2010). On the other, as we have seen, the meanings of sonic symbols – the sound-meaning structures, using the term suggested by Tuuri and Eerola – are not arbitrary, but grounded in embodied experience of which the brain is only one part. Even the most high-level and abstract concepts and metaphors that make up the activity of thinking can according to the embodied view be traced back to particular bodily experiences. Importantly, these experiences are not only constituted through the biological body or its physical habitat, but are dependent on the social, cultural, and political reality within which the body exists (Roddy & Furlong, 2015).

On a number of accounts, embodied cognition can be aligned with the critical hermeneutics of Drucker, making it a plausible theoretical framework for humanistic sonification practices. This is not necessarily a surprise given that they both to some degree draw inspiration from related continental-philosophical traditions. Just as Drucker, the embodied paradigm shuns Cartesian dualism (Roddy & Furlong, 2015), instead favoring monistic phenomenological perspectives drawn partly from Merleau-Ponty and – by extension – Heidegger (Gossmann, 2010), thinkers that are important in the critical-hermeneutic tradition as well. Further, the embodied view shares with Drucker the conviction that it is not possible to transfer meaning in a “mechanistic way” (Drucker, 2020, p. 44). The listener/reader rather partakes in the meaning-making process, which is thereby shaped by subjective embodied and situated experience. This also means that the listener/reader is understood as fundamentally active: “The embodied perspective embraces the listener as an action-oriented intentional being making sense of the world.” (Tuuri & Eerola, 2012, p. 149) Such a view favors the idea that sounds hold the potential for a multitude of possible interpretations, rather than a single correct one to be uncovered by the listener; that particular sounds evoke a “diversity of meanings” and “affective responses” (Tuuri & Eerola, 2012, p. 150). Put differently, the act of listening to a sonification can be seen as negotiation between sound and listener, as an “intervention” into a “field of possibilities” (Drucker, 2020, p. 45).

At the same time, in the sonification literature making use of embodied cognition, there is a tendency to embrace utilitarian and instrumental perspectives on sonification design, focusing on an “efficient completion of tasks” rather than the “sustained interpretative engagement” (Drucker, 2020, p. 133) favored by the Druckerian approach. This is perhaps most apparent in a paper by Roddy and Furlong (2015), which sketches a “sonification listening model” based on “models of embodied cognitive meaning-making faculties” (p. 181). Here, the aim is to use embodied cognition in order to design “effective sonification mapping strategies”. Through the insights of embodied cognition, they argue, it becomes possible to factor in “underlying biases that exists in a listener” (p. 187), thereby facilitating the creation of “more effective auditory displays” (p. 181) (a similar tendency is visible in the less practically-minded, more theoretical approach of Roddy & Furlong, 2013). Beyond this, it is also worth taking into account an argument by Grond and Hermann (2014, p. 45) regarding the limitations of embodied cognition. They suggest that the perspective of embodied cognition is less well suited for theorizing reflective and abstract types of listening “that involve higher cognitive resources”, offering “higher levels of abstraction from first level significations” and “more emphasises thinking than doing”. Embodied cognition is thus perhaps less usable for understanding the slow, premeditated and thoughtful process of the close reading (“close listening”?), which is the preferred method of knowledge production for the hermeneutic mode of inquiry. It is precisely through such a process that the ambiguities, contradictions, and multitude of perspectives inherent in an object of study are able to come to light.

For these reasons – as well as for the simple reason that the theoretical framework of this thesis is grounded in continental philosophy rather than cognitive psychology – another theoretical approach will be the focus for much of the remaining parts of this chapter: the approach of *reduced listening* and of *listening modes*. This approach, which appears in a number of texts throughout the sonification literature, was originally developed in the writings of the French composer Pierre Schaeffer, and has been further elaborated upon by his countryman, the theorist Michel Chion, whose work revolves around the use of music and sound in film (Vickers, 2017). It shares with embodied cognition a diminished focus on the objective qualities of sound and signal, also dealing mainly with the subjective experience of listeners. According to Grond and Hermann, this shift is important since “[t]he kind of information that we receive is not equal to *what* we perceive, but depends on *how* we perceive it”, suggesting further that “the information content of a sonification needs to be found in the ear of the listener and not only in the signal into which the data are converted” (p. 41, italics in original). However, when compared with embodied cognition, reduced listening offers a clear-cut phenomenological approach, sketching a phenomenology of listening.

6.3 Phenomenology of listening

Pierre Schaeffer was an influential name in post-war experimental and electronic music circles. His main contribution lies in the invention of the compositional practice of *Musique concrète*, a style of music which involves the recording of sound onto magnetic tape. These sounds are then arranged and manipulated in various ways in order to create coherent pieces of music. In Schaeffer’s theoretical work, a chief concern was to understand the ways in which listeners could engage with this new type of music. He was asking how it would be possible to create meaningful experiences in the encounter with unfamiliar sound worlds, populated by what Schaeffer denominated sound objects ("objets sonores"). For this purpose, Schaeffer postulated a method of listening that he named reduced or acousmatic listening. Drawing inspiration from the phenomenology of Edmund Husserl, the aim of this type of listening was to shed all preconceived notions of a given sound, trying instead to directly focus on the sound in itself, on its raw phenomenological characteristics (Chow, 2019). This included avoiding taking into account the physical object that had caused the sound. In Schaeffer's own words, acousmatic listening "emphasizes the perceptual reality of sound […] by distinguishing it from its methods of production and transmission" (Schaeffer, 2017, p. 64).

This type of listening can be said to embody an ideal according to which musical sounds do not signify anything non-musical, beyond the pure phenomenal characteristics of the sounds themselves. Clearly, it is an ideal that can be said to diverge from the signifying purpose of sonification and auditory display, where sound is ultimately meant to communicate relationships, occurrences, or structures within sets of data. However, Grond and Hermann (2014) argue that the practice of reduced listening has the potential of lifting "cultural and experiential biases", offering the possibility of freeing the sound from "a first degree of signification" (p. 43). Their point is that new types of signification might be opened up by approaching sound with – so to speak – fresh ears. Further, reduced listening is only part of Schaeffer's wider theory of listening, which comprises, as was mentioned above, a number of different *modes of listening*. Schaeffer postulates four such modes: Ouïr, Écouter, Entendre, and Comprendre. These modes are in Schaeffer (2017) translated as: To perceive aurally, To listen, To hear, and To understand. These are arranged in accordance with two axes: subjective–objective and abstract–concrete, as is seen in the **Figure 1** (Valle, 2015).

4. TO UNDERSTAND (comprendre) - for me: signs - in front of me: values (meaning-language) Emergence of a sound content and *reference to, encounters with*, extra-sonorous concepts.	1. TO LISTEN (écouter) - for me: indicators - in front of me: external events (agent-instrument) Sound *production*	1 & 4: objective
3. TO HEAR (entendre) - for me: qualified perceptions - in front of me: qualified sound object *Selection* of certain specific aspects of the sound	2. TO PERCEIVE AURALLY (ouïr) - for me: raw perceptions, vague idea of the object - in front of me: raw sound object *Reception* of the sound	2 & 3: subjective
3 & 4: abstract	1 & 2: concrete	

***Figure 1**: Shaeffer's listening modes*

According to Grond and Hermann (2014), listening modes can inform the creation of sonifications by allowing one to identify how various designs will favor one or another way of listening. For example, all sonifications are first perceived as an audible event (Ouïr). When listening more closely (Écouter), the listener will try and find or figure out a cause or source for the sound. Simpler sonification designs might want to focus on these fundamental levels of perception. For instance, a sonification designed for seismologic monitoring might not have use for more than the simple signaling of the presence of irregular seismic. The listening mode of "understanding" (Comprendre) denotes the influence of extra-sonorous influences such as language or culturally established musical motifs while the mode of hearing (Entendre) involves a more active and concentrated decoding of non-linguistic sonic information. For this reason, hearing is probably the mode favored by most sonification designs since it allows the listener to pay attention to all aspects of complex sonifications which comprise multiple layers of signifying sound (Grond & Hermann, 2014; Schaeffer, 2017). Chion (1994) points out that the mode of hearing is rather demanding for the listener, and that it therefore generally requires repeated hearings of the same material. According to Grond and Hermann (2014), it is also a type of listening for which the phenomenological approach of reduced listening provides a better understanding than embodied cognition. They argue that the mode of hearing has the potential of becoming "detached from the immediate meanings of the connotative embodied levels", and that it therefore "offers the possibility to engage with the unknown, for instance when exploring the complex sound of sonifications which aim at representing complex data relations." (p. 45)

In a number of instances in the sonification literature, the original conception of listening modes as developed by Schaeffer has been further elaborated. In these cases, listening modes are combined with an embodied-cognition approach, also suggesting a set of new modes (see especially Tuuri & Eerola, 2012; Vickers, 2017) In part, these elaborations have drawn on the work of Michel Chion (1994, 2012). While it is beyond the scope of this thesis to discuss all these theoretical variations, it is useful to note that the literature repeatedly underlines that the listening modes are not to be seen as mutually exclusive, but rather as complementary. Already Schaeffer emphasized that the listener tends to almost instantaneously cycle through the modes, rather than simply "inhabiting" one of them. It is through this cycling that patterns in data become visible and an understanding gradually emerges (Grond & Hermann, 2014; Schaeffer, 2017). Further, Tuuri and Eerola (2012) argue that one principal benefit of applying a framework of listening modes to sonification "lies in its ability to account for the heterogeneity of different, even contradictory, levels of interpretations, emotions and other meaningful experiences on the basis of the same physical sound." (p. 138) This emphasis on interpretation as a gradual, meaningful, heterogeneous, and even contradictory process signals a clear move away from a paradigm in which the listener is perceived as a passive receiver of sonically encoded information. The type of listener that this implies can be correlated with the way in which Drucker (2020) understands the reader: as a situated and active party in a complex process of negotiation. This process is the manner in which the interpretation of a text, an image, or composition of sounds comes into being, for Drucker as well as for the phenomenological approach to listening.

This is further underlined by Grond and Hermann (2014), who contend that the phenomenological approach can be differentiated from (natural) scientific understandings of listening, which focuses on "quantifiable signal properties and their behavioral, neurobiological or psycholinguistic correlate" (p. 45). They argue that both these approaches have advantages and that they are potentially complementary, depending on the purpose of a given sonification design. Possible purposes are divided into two overarching categories: normative and descriptive. Sonifications that fall under the normative category are closely aligned with the scientific approach, where the use of sound is "meant to inform the user about well-defined events or actions" (p. 46) and "helps to achieve a predefined or desired goal" (p. 47). For a humanistic approach to sonification, the descriptive purpose is most likely of greater interest. As can perhaps be deduced from its name, a descriptive sonification strives toward describing data structures rather than simply transmitting them; it is meant to "make us think" and to create an intellectual articulation of what is heard (Grond & Hermann, 2014, p. 46). This means that greater attention has to be directed at the sounds themselves, which are not simply representing an underlying set of data, but are presented as a method for interpreting it. The descriptive sonification further "supports reflection on sonic details and structures as a prerequisite to relate them to data properties" (p.47). This focus on the raw sonic properties of sonification brings the practice of reduced listening back into view.

6.4 Music and aesthetics

Apart from the points listed above, Grond and Hermann (2014) highlight one further aspect of the theory and practice of reduced listening that sets it apart from (natural) scientific approaches: its close connection with the sonic arts. If perspectives on sound and listening originally developed by Pierre Schaeffer is to be implemented within the context of sonification, they argue, their firm roots within the theory and practice of music need to be thoroughly discussed. As we have seen above, music is one potential area where sonification comes into contact with the practices and theories of the humanities. Apparently, judging from the amount of ICAD papers that discuss it, music and its relation to sonification is also a hard subject to avoid within the sonification community. The most common overarching theme running through these papers relates to the implementation of musical elements and methods for music composition in the context of sonification design (Bonet, 2019, 2019; Diniz et al., 2010; Last & Usyskin, 2015; McGee & Rogers, 2016; Neuhoff & Wayand, 2002; Rönnberg & Löwgren, 2021; Scubert et al., 2011; Scubert & Preti, 2011). Another major theme involves discussions around the roots of sonification within musical history (Gena, 2012; Schoon & Dombois, 2009; Straebel, 2010; Taylor, 2017), while a range of papers and articles comprise presentations of musical pieces that, in some way, involve the practice of sonification (Barrass et al., 2006; Eacott, 2012; Grimm et al., 2011; Leonard, 2010; Lindborg, 2018; Quinn, 2001). The role of music also raises the wider issue of aesthetic elements within sonification and if/when sonification can be considered art, which is discussed in a number of ICAD papers (Barrass, 2012; Barrass & Vickers, 2011; Grond & Hermann, 2012; Jeon et al., 2013; J. Parker, 2015).

As one of its fundamental topics, any discussion on the relationship of music to sonification raises the issue of signification within or through music. This is a broad and complex subject with a long history, and it can only be touched upon briefly within the confines of this thesis. However, given that the sonification literature recurrently discusses historical ideas concerning the representation of non-musical themes through music, it can be helpful to provide a short overview. If nothing else, this will serve to highlight that the (sonic) arts are just as much a part of the "cultural history" of sonification as the sciences (Schoon & Dombois, 2009) and that these arts therefore have played an important role in the forming of sonification as a field.

Within the classical western tradition of instrumental music, there has traditionally existed a differentiation between so-called program music and absolute (abstract) music. While the latter is not meant to reference anything non-musical, program music aims, at least in part, at the narration or expression of extra-musical meaning. An early – and very famous – example of program music can be found in Beethoven's Sixth "Pastoral" Symphony. This musical composition included the imitation of various natural phenomena such as birdsong, a thunderstorm and flowing streams, thereby painting a portrait of the natural world through musical sound alone. This and many other examples of program music can be seen as expressions of 19th century romanticism, which harbored ideas of an unmediated access to nature through music, art, and poetry. From a musicological perspective, Straebel (2010) suggests that there are similar notions at work within today's sonification community. Just like program music, he argues, sonification practices tend to aim at remediating data into sound in order to "make the world understandable by translating natural phenomena to our senses for immediate perception" (p. 292). Taylor (2017, p. 58) follows a similar line of thought, suggesting that sonification in some sense can be seen as an "updated version" or as a generalization of program music.

With the advent of electronic, experimental, and computer music in the post-war period, modernist composers began using data as a direct source material for creating music (Gena, 2012; Straebel, 2010). If one wanted to mention an example that is recurrently discussed in the sonification literature, one could point to Alvin Lucier's 1965 piece Music for Solo Performer, in which amplified brainwaves stimulate and activate a set of percussive instruments (Straebel & Thoben, 2014). Today, driven by technological development and by an increasing availability of data, there exists an expanding genre of "sonification-based music", especially within the field of sound art (Schoon & Dombois, 2009; Vickers, 2017). Representations of this genre will be discussed in the subchapter on examples below. Here, focus will instead be directed toward issues raised by an approach that combines artistic agency with aims of representing or expressing scientific data. For one thing, it raises the question of how and where to draw a border between art and sonification, and when and if such a border is necessary. In her study of sonification as a field and a community, Supper (2012a) shows that this has been an area of contention since the early ICAD conferences. This controversy is not least visible through the various definitions of sonification that are circulating. One of the most widely used definitions is provided by Hermann (2008) (for examples, see Last &

Usyskin, 2015; Ludovico & Presti, 2016). This definition – aimed at providing necessary and sufficient conditions for sonification – argues that sonifications need to be reproducible and systematic, thereby being able to reflect objective relations and structures in the underlying data. According to Supper, it aims at reducing subjective intervention, favoring instead a "mechanical objectivity". Therefore, Hermann's definition draws a sharp line between art and sonification, arguing for sonification to be strictly scientific. This, however, remains controversial, and other definitions remain open for a more comprehensive influence from the arts (Supper, 2012a).

Another area of contestation within the field regards the role and influence of aesthetics. On the surface, there exists a broad consensus within the literature that aesthetic forms of knowledge are a crucial part of the practice of sonification design. For instance, during the early ICAD conferences, designers were encouraged to work with composers when creating sonifications (Barrass & Vickers, 2011). One example of this is that in the influential Sonification Report (G. Kramer et al., 1997), which was a document created in order to present the field of sonification for the American National Science Foundation, it is underlined that the field is strongly interdisciplinary and that it needs to integrate contributions from design and from the arts. However, in the sonification literature, there is no common understanding regarding the type and content of these contributions, and no unified conception of aesthetics, once again reflecting, among other things, the multidisciplinary nature of the field. While clearly a continuum, Neuhoff (2019) suggests that there are two overarching approaches: an empirical and an artistic. For the empirical approach, musical or aesthetic influences are subordinated to the overall intent of using sonification as "a scientifically legitimate way of representing data" (p. 328). An example of this approach can be found in Vickers and Hogg (2006), who argue that the inclusion of musical elements should serve making the transmission of information content as effective as possible. Musical-sounding sonifications tend to be more pleasant to listen to, thereby reducing annoyance and fatigue, making it possible to "attend carefully" to the sounds and what they are meant to represent. At the same time, they warn against ending up at the other end of the spectrum and being "seductively musical" since this might distract the listener from the information that is being conveyed (p. 215). In other words, for the empirical approach, aesthetics are deemed useful as long as their concerns are not allowed to become too prominent. Similar approaches to musical and artistic sonification design can also be found in for instance Rönnberg and Löwgren (2021), Last and Usyskin (2015), Jeon et al. (2013).

6.5 Musical sonification and humanistic approaches

Sharing views with Grond and Hermann (2014), as described above, Neuhoff (2019) makes the point that it is the *purpose* of a sonification that should decide its *type*. In some cases, empirical sonifications are best suited for the task at hand. However, Neuhoff argues that in other cases and for some types of data, it is simply not possible to stay "empirically faithful" to underlying data relations. Here, the aesthetic aspects of sonic representation should be embraced through an artistic approach which does not aim at being "precise". The listener should instead be given a “sense” of the data, which should further stimulate curiosity and facilitate a multitude of possible interpretations. A similar line of reasoning is put forward by Gresham-Lancaster (2012). He argues that it would be a mistake to frame sonification only in terms of “scientific method”, as is advocated by Hermann (2008). Among other things, he questions whether it in many cases is preferable or even possible to map data onto sound in a way that is wholly transparent and reproducible. While a sonic artifact that bears no relation to a set of data clearly cannot be named “sonification”, a too strict mapping of data to sound often yields unsatisfying results. Such sonifications will risk appearing unengaging to the listener, thereby making the intended act of communication more difficult. As an alternative, Gresham-Lancaster suggests that for the field of sonification to reach its full potential, it should strive to involve “the craft and art of music composition” (p. 207). This implies shedding claims of producing exact representations of data. Instead, by allowing science and art to “work together”, it becomes possible to “discover the hidden world in the augmentation of reality that is embedded in the act of sonifying data sets” (p. 208). The strictness of the scientific method can thereby potentially be transcended, Gresham-Lancaster argues, opening up for the discovery of “signifiers buried in each data set that carry a beauty and a meaning” (p. 208). He thereby highlights the design of sonifications as an interpretative act, producing only one out of many possible expressions of the structures within a given set of data. This ideal is concisely summarized: “A well-crafted sonification would ideally convey […] a unique auditory perspective on the information that is being sounded” (p. 209).

It is not difficult to see how these theoretical positions align closely with the understanding of humanities data perceptualization advocated by Drucker (2020). For one thing, Drucker favors the involvement of aesthetic modes of knowledge and welcomes influences from the arts, something which should reasonably also include music, even though this particular artform is not explicitly mentioned by Drucker. Further, she remains wary of drawing on methods developed within the empirical sciences for dealing with humanities data and research subjects. As we have seen, Drucker’s concern is that such methods will obfuscate the ambiguities and contradictions that is often the core focus of humanistic research. Rather than the “this is” of the natural sciences, she advocates for the creation of tools for data perceptualization that conjures a “field” of possible interpretations. As should be clear by now through a number of examples, musical sonification is presented in the literature as just such an alternative to empirical and (natural) scientific sonification design. As with Drucker, the theoretical positions presented above also exhibit a skeptical attitude towards to the paradigm of *data representation* (remembering that Drucker instead promoted “nonrepresentation”), with authors preferring instead to talk about “augmentation” through data, or of creating “a sense” of underlying data relations. As a final example, one could also mention Bleeker et al. (2020, p. 5), who suggest that sonifications should be understood as ”sites where understanding may be generated”, and not primarily as representational devices.

One further and crucial aspect of Drucker’s critique underlines that it is not only the process of visualization or perceptualization that entails interpretation, but also the earlier stages, which involve the selection and manipulation of the “underlying” data. Within the field of musical sonification, a similar line of thought is put forward by Parker (2015; 2016). While working on a project which involved the composition of music based on data extracted from a compost heap, she discovered that while it might seem as if using a predetermined data set would leave no room for the creative agency of the composer, every step in the process actually required such agency. Even the initial choice of data set, as well as the choice regarding which aspects of the data are to be used as "raw material", Parker writes, will need to involve conscious decision-making. Furthermore, once the composer starts making aesthetic choices, interpretation is required since a given understanding of the data is to be expressed through sound (J. Parker, 2015, p. 98). In other words, while more scientifically minded sonification ideally will aim at reducing such subjective interventions at the outset of the design process (as in Hermann, 2008), artistic or musical sonification will, Parker argues, have to embrace them.

Clearly, if a design process is thoroughly interpretative and involves aesthetic choices on every step of the way, it will risk becoming less transparent to a listener or an outside observer. However, while acknowledging that there is truth in this, Gresham-Lancaster (2012) argues that it is still possible to make artistic sonifications "reproducible". More important, however, is to establish a relationship of trust between designer/composer and listener. Such trust does not require that "the perceptual linkage" is "obvious or even apparent". Rather, it should make possible for the listener to have faith in that "what they are hearing is the direct transference of data" (p. 208). Further, drawing on Drucker, one can argue that the transparency favored by a general "scientific method" is never really possible anyway, especially when dealing with humanities data and research subjects. This means that the issue of trust, and therefore also of scientific honesty, is a crucial aspect of any process of data perceptualization.

However, this should not mean that "anything goes". If a too strict mapping of data into sound will tend to lead to unsatisfying results, a sonification that makes it impossible for a listener to get any sense of a relation to the set of data being sonified will risk undermining this above mentioned trust. Clearly, a given set of data can potentially yield any number of musical sonifications, with the possibility of making use of an almost limitless repertoire of musical genres and compositional techniques (for examples of this, see Barrass et al., 2006). As a consequence, discussions regarding the extent of the agency of the composer or sonification designer, and on methods for staying true to the communication of data, are recurring in the literature on musical sonification. For instance, regarding the piece *Music by Oceans*, in which data collected from ocean probes are sonified, composer Stef Veldhuis describes striving for a kind of collaborative approach, where the composer and the ocean is responsible for 50% each (Bleeker et al., 2020). A similar line of thought runs through the compost data sonification of Parker (2015; 2016), in which biological and chemical processes are described as a kind of creative partner rather than simply as underlying material for data extraction. Drawing on suggestions made by Bleeker et al.(2020), it might be useful in these cases to conceptualize the composer/sonification designer as a form of *curator*. Rather than creating a piece of music "out of nothing", it is a question of constructing meaning through a process of selecting and framing. As is described by

Stef Veldhuis, just as music is used for stimulating emotional and associative responses, the data will also inspire new ways of working and composing (p. 1094).

Another potential benefit of musical sonification lies in the manner in which it perceptualizes temporality. As we have seen, Johanna Drucker is critical of the way conventional timelines visualize time as "unidirectional in its flow, homogeneous in its metrics, and continuous". Humanities research, she argues, instead needs to reflect time as relational and heterogeneous. Further, it must model the "complexities of lived, reported, constituted, and produced temporality in human documents" (Drucker, 2020, p. 114). Perhaps the use of musical time in sonifications would mean providing an alternative way of modeling temporality, beyond standardized measurements? This at least is the argument made by Tsuchiya and Freeman (2018). For one thing, they make the point that musical sounds are not perceived simply through the linear progression of "clock time". Rather, even simple musical pieces are experienced in multiple overlapping time scales, involving the complex interplay between meter and rhythm with musical characteristics such as melody, timbre, and overall musical structure. With advanced compositional techniques such as polyrhythm and polyphony, even more multifaceted temporal structures are made possible. Taken together, musical time has the potential of allowing for a "polyphony of viewpoints", a coexistence of time scales of which "absolute time" or clock time is only one.

These ambiguities of musical time are sometimes perceived as a problem within data sonification. If they have not made designers avoid using musical elements altogether, they have prompted the employment of "tick marks" or a static metronome. However, Tsuchiya and Freeman cautions against such approach, arguing that it superimposes an artificial rhythmic structure that may cause "a false sense of periodicity" (p. 43). Once again, one has to return to the notion, developed by Neuhoff (2019) as described above, that it is the purpose of a given sonification design that determines its type. For sonifications that aim at transmitting simple information as unambiguously as possible, it might be wise to avoid relying on musical elements since these come with a set of temporal complexities. On the other hand, from the perspective of Drucker's critical hermeneutics – for the purpose of temporal modeling – musical sonification appears to provide an attractive way forward. Do not music and musical time seem to have much in common with the way Drucker describes the temporality of narratives? It flows in "segments, chunks, with gaps and breaks". Further, it is not governed by any standard metric, but changes scale constantly, "stretching, shrinking, becoming compressed or extended" (Drucker, 2020, p. 115), and so on. Clearly, the relationship of musical time with temporality and interpretation of data is very complex. It merits further investigation beyond the brief mention that has been presented here.

While it should be clear by now that musical sonification provides interesting strategies for the perceptualization of humanities data, the literature also provides a number of skeptical perspectives that need to be mentioned and taken into account. One such criticism focuses on the cultural specificity of musical forms of expression, as for instance discussed in Worrall (2019) and Vickers and Hogg (2006). According to Worrall (p. 17): "...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.” Music, as all artforms, is culturally mediated and socially situated. Accordingly, a set of musical forms that is deeply meaningful to people within one context might be difficult to understand or interpret within another, limiting the audience to which a musical sonification is able to communicate. Worrall points out that this also has a temporal aspect: as societies change, so does music, resulting in a failure of older forms to attract the interest of younger generations. As a way of counteracting this tendency, Vickers and Hogg (2006) suggest applying techniques borrowed from narrower or avant-garde types of music such as Electro-Acoustic Music (EAM) or Musique Concrète, arguing that these are less culturally specific than pop, classical or “anything we already recognize” (p. 212). As for the tendency of specific forms of music to fall out of fashion and lose its relevancy to broader groups of people, one might ask if there are any sonic forms that can be applied within a sonification design that might be immune to this.

Related to the problems regarding the cultural conditioning of music is the issue of musical training. A number of texts argue that while not an unconditional prerequisite, such training will tend to drastically enhance the capability of interpreting musical sonifications (Mauney & Walker, 2007; Neuhoff & Wayand, 2002). Neuhoff (2019) draws attention to the large representation of people with a musical background within the field of sonification. This, he claims, often leads to a failure to take the capacities of “naive” listeners into account when designing sonifications, expecting more from them than is actually possible. However, others argue that the ubiquitous nature of certain popular musical forms make them ideal for use within the context of sonification, given that they are able to communicate with listeners on a more intuitive level (Last & Usyskin, 2015). It might also be questioned whether there are any forms of sonification whose interpretation do not require any type of training whatsoever. It is not as if most sonifications will be self evident to an unprepared listener (S. Ferguson & Cabrera, 2008). Vickers and Hogg (2006) also point out that the same is true for data visualizations, the interpretation of which generally requires both experience and training. One recurring point made in the literature is that the interpretation of a sonification is an iterative process, as good as always requiring repeated hearings, at least when considering the sonification of complex and multivariate sets of data (see for instance Worrall, 2019).

Another strain of criticism focuses on a perceived lack of aesthetic qualities in musical sonifications. For instance, Vickers (2017) asks whether there is a risk of musical sonification becoming a kind of “graphic design” of music: something that is utilitarian but perhaps not particularly interesting as art and/or music. Devroop and Titlestad (2021) make a similar claim, but are more pessimistic regarding the possibility of creating truly musical sonifications. They argue that the fundamentally divergent aims of music and sonification make it if not impossible, then at least very difficult to create sonification pieces that are musically pleasing. In relation to these strains of criticism, one must once again ask what the overall purpose and ambition of the sonification is. If the aim is to use musical components simply for the sake of enhancing the communicative capabilities of a sonification design, this need not be a problem. In these cases, aesthetic qualities are of subordinated importance. If, on the other hand, one wants to create a sonification that also works as music, the challenges involved when trying to remediate data into enjoyable music would need to be dealt with. One potential manner of approaching this problem is discussed by Parker (2016). She presents a manner of creating musical sonifications which she prefers to label "musification", something she considers to be a more "humanized" form of data sonification (p. 122). In order to create successful musifications, one needs to shed strict dependencies on data, creating music that is based on a less "literal" reading of the data. She argues that "the success or failure of a data musification should not hinge on the basis of its being a note-to-note translation of datasets". Instead, it hinges on the "artistry in adapting a particular dataworld", playable by musicians and "to be enjoyed, and hopefully also understood in some way by the audience."

6.6 Sonification examples

As was mentioned already in the beginning of this chapter, sonifications based on humanities or social sciences data are rare. Instead, natural-scientific data of various kinds are by far the most common basis for existing sonification designs. However, the fact that a given sonification is derived from non-humanities data does not necessarily mean that it is based on a natural-scientific or positivist understanding of information transmission and knowledge production. Neither does it mean that nothing can be learned from the sonification from a humanities perspective, as was argued already in the introduction to this thesis. In fact, in the literature, there exist a wide range of approaches and perspectives that in some cases come quite close to the type of epistemological outlook promoted by Johanna Drucker. In this subchapter, a few examples of such sonification designs are briefly described and discussed, highlighting the ways in which they can serve as inspiration for potential future humanities sonifications. These examples mostly, but not exclusively, fall into the category of musical sonification.

Many such examples can be found in the annual concert given in connection with the ICAD conference. In these concerts, designers are given an opportunity to demonstrate sonifications and auditory display systems. In 2006, the concert, which was given the name "Global Sound – The world by ear", had as its special focus social and historic data. de Campo (2009; 2011) discusses the sonifications presented at the concert, and shows how they manage to shed new light on societal and historical data and on the social conditions that the data reflect. For instance, in the piece *Guernica 2006*, Guillaume Potard sonifies data covering population growth and wars over the last 2000 years. Another piece of interest is Julian Rohrhuber's *Terra Nullus*. In this sonification, data mapping of socio-economic conditions in countries across the globe are used. However, rather than sonifying what is present in this data, Rohrhuber's sonification makes audible the values that are missing from it. The piece thereby puts focus on an often unavoidable feature of sets of data – that they are incomplete, full of gaps and the result of a process of selection – something which according to Drucker (2020) tends to be concealed by standard types of data visualization and perceptualization.

However, the most relevant piece in the context of this thesis is perhaps *Navegar É Preciso, Viver Não É Preciso* ("Sea-faring is necessary, living is not"), created by de Campo himself in collaboration with Christian Dayé (also described in de Campo & Dayé, 2006). The sonification explores navigation as practice and knowledge system, highlighting the historical changes it brought when European seafarers made use of it for exploration and conquest around the globe. The basis of the sonification are two juxtaposed data sets. The first set depicts contemporary socio-economic conditions of all the world's countries, describing things such as relative wealth, income inequality, and access to drinking water. The other data set outlines, through spatial and temporal data, the historical route taken during the expedition of Magellan. When sonified, the two data sets make audible current socio-economic realities in countries along or close to Magellan's route, as the listener follows its path. Sound-wise, the sonification is composed of a number of separate sound streams. For example, one sound stream aims to capture the population density in the areas along the route. Higher population density is expressed through making the sound "thicker", and vice versa. Another sound stream represents GDP through the modulation of pitches. Lower pitch means that the area is poorer, and higher pitch richer. The distance from the ship is expressed through making the sounds more or less blurred or vague: the farther away, the more blurred the sound.

There is no given interpretation of this piece, and the listener is not given any guidance regarding how to make sense of the juxtaposition of contemporary socio-economic data of countries along Magellan's historical route. de Campo states that the use of data derived from a single year – representing a single snap-shot in time – makes it "free of the idea of historical progression" (de Campo, 2009, p. 163). As such, it can be seen as a strategy for avoiding conventional representations of temporality, in which time flows or progresses in a linear manner. Instead, a relation between two points in time – separated by several hundreds of years – is highlighted. This can be said to come rather close to the type of modeling of temporality championed by Drucker. As we have seen, she is critical of the way time often is represented as unidirectional and homogeneous, arguing instead for relational presentations of time. Further, through the use of complexity, and through paying attention to aesthetic aspects, de Campo and Dayé can also arguably be said to strive for the type of "sustained interpretative engagement" that Drucker argues should be a core aim of humanistic data perceptualization. As de Campo puts it, when designing the sonification they "deliberately chose rather high display complexity". The idea was to encourage "repeated listening", "as audiences tend to do with pieces of music they enjoy" (p. 168). With complexity and repeated listening comes also a greater range of interpretative possibilities.

It is not only the type of data, or the scientific domain to which a set of data can be said to belong, that decides the epistemological outlook of a given sonification. As we have seen, more than anything else, this outlook is dependent on the general purpose of the sonification. In the literature there are a range of examples of natural-scientific sets of data being used in sonification designs that favor interpretative approaches, investigating questions that are best answered using humanistic modes of inquiry. This is for instance evident from the manner in which astronomical data is utilized in a number of designs. In these sonifications, the purpose is, more than anything else, to explore the history of ideas surrounding astronomic exploration and the cultural understandings regarding the place of humans in the universe. One example of such approach can be found in the sonification-based soundtrack for the film *Rhythm of the Universe,* "...a shifting collage of music, videos, visualizations, and sonifications" (Ballora, 2014, p. 1). The musical content of this soundtrack is based on data derived from cosmic phenomena such as pulsars, gravitational waves, and solar winds. However, while the sounds are aimed at reflecting and perceptualizing aspects of these phenomena, the intended audience is much wider than the specialists capable of actually understanding and interpreting the natural-scientific meaning of the data. The overarching purpose of the sonification, described by its designer as a "poetic and scientific speculation on humankind's innate desire to understand the cosmos" (Ballora, 2014, p. 1), is to invoke dramatic effects, while at the same time being informative. As is noted by the sonification designer, aesthetic interpretations when visualizing astronomic data are quite common – vital for creating "informative renderings" that make sense for a broader group of people – for instance involving the coloring of astronomic photographs. This is due to the fact that the enormity of the data makes it impossible for the human mind to take in.

Further examples of similar approaches can be found in sonification pieces described by Leonard (2010) and Grimm et al. (2011). Leonard outlines a project that involves NASA scientists, aiming at sonifying solar system and planetary science data. The data is rendered into sound using methods derived from electro-acoustic composition, creating a "sonification of naturally occurring patterns" (p. 1). However, the main goal is not to study the scientific data as such, but rather to explore a history of ideas: "The composition explores ancient questions related to the poetic use of pattern, symmetry and ratios. The piece leverages our study of the works of Pythagoras, Hildegard of Bingen, Bartok, Coltrane and Ikeda, all of whom explored these ideas." (p. 1) Put differently, the overarching idea of the piece is to put the data into dialogue with philosophy and with the music by musicians such as Bartok and Coltrane. In Grimm et al. (2011), the use of a musical material is even more strongly pronounced. Here, the material or "data" for the "sonification" is an obscure piece (in the style of an "In Nomine") for viola da gamba-ensemble by the English renaissance composer Mr. Picforth. The piece is thought to represent or express ideas regarding the harmonic nature of the cosmos – a "harmony of the spheres" – that were common at that time. The sonification simply consists of a contemporary ensemble performing the In Nomine, the sound of which is processed live through electronic means to further emphasize the interpretation of the ideational content of the music.

These three projects show a diverse range of sonification practices: the project discussed by Leonard can be understood as a quite straightforward sonification-based electronic composition, while the piece described by Ballora is part of a much wider multi-media project. In Grimm et al., the aim is to try to illustrate or discuss a set of historical ideas by using a traditional viola da gamba-composition. If nothing else, it (once again) shows the wide array of possibilities in relation to a given type of data, especially if one employs an artistic or musical approach, which is the case in all three projects. In Grimm et al., it can probably be questioned whether the piece even can be considered a “sonification” at all. However, the intention with the piece is to discuss a natural-historic set of data (the positions and movements of the planets in our solar system), and given that the piece was presented at the 2011 ICAD conference, there is at least a relation to the wider field of sonification.

Another type of natural-scientific data that is prominently discussed within the literature as a basis for sonifications that make visible a range of perspectives comes from climate science. In fact, this review has found that climate data is one of the most commonly used data types within the field. The reasons behind the popularity of this particular type of data, relating to the issue of climate change, are multiple. On a technical level, the temporal nature of the issue – the fact that climate change evolves over time in a measurable manner – makes it ideal for the medium of sound. As we have seen, time-series data is well suited to be expressed through sonification (Last & Usyskin, 2015). Further, in some cases, the use of sound elements derived from traditional musical language is perceived as useful for communicating the content and meaning of a set of data. This is the case with Bonet (2019), in which dissonance is applied in order to signal alarm. However, more importantly from a humanities’ perspective is the fact that climate change and related environmental issues by their very nature tend to involve a complex interplay of perspectives. While the process of climate change can be described by natural-scientific language and methods, the study of its impact on human societies and the interplay of these societies with the natural world will often need to be interdisciplinary, taking into account outlooks from the social sciences and/or the humanities. Finally, being one of the pressing issues of our time, there is a perceived need of communicating climate and environmental science data to the wider public. In relation to this, sonification is used as a means for science communication, the reasoning being that sound has the capacity of engaging people.

All these various aspects of climate data sonification can be said to be visible in the piece *The Locus Wrath*, as described by Lindborg (2018). *The Locust Wrath* is a multimedia dance performance on the topic of climate change. In it, sonification of climate data is used as the basis for a musical composition created in close collaboration with the choreographer and the dancers. In order to facilitate the collaborative process, an interactive sonification software was created which allowed for a continuous process of tweaking and redesign. The data itself consists of time series covering various weather-related trends – precipitation, wind speed, temperature, etc – as they have been recorded in the past, but also as they are expected to evolve in the future through predictions stretching towards the end of this century. While the main focus of the whole project is the performance of the dancers, the musical sonification fills a dual purpose. To begin with, it needs to guide the dancers in their movements, meaning it must communicate musical ideas that are possible to dance to. However, given that the composition also strives for the sonification of data, it must also successfully convey the content or the meaning of that data to its listeners, that is, to the dancers as well as to the audience.

From the theoretical perspective of this thesis, the ideas and design choices guiding the sonification for *The Locust Wrath* are interesting for a number of reasons. Early on in the design process, the creative team decided to avoid using a “purist audification approach", meaning that the data would be compressed to fit the time frame of the performance, in which for instance one minute of sound/music would represent one year in the data. Such approach was deemed yielding a result that is "undramatic", and therefore not fitting the narrative thrust of the performance (Lindborg, 2018, p. 470). Instead, it was decided that the sonification would focus on specific years or limited time periods, based not on their place on a timeline, but on their cultural, political and/or historical significance. This would involve shedding a simple representational method, where the sonification system is thought to passively reflect the data. Instead, a methodological approach was chosen that is dependent on the active aesthetic and interpretative interventions by the designer/composer. According to Lindborg, this approach meant that "[t]he technique of audification problematizes temporal relations between (imagined) reallife properties of the original phenomenon that the data represents and the (actual) sonic gestures in the auditory display." (p. 470)

As can be seen, the way temporality is approached in *The Locust Wrath* shares similarities with the method used by de Campo and Dayé: rather than opting for a linear chronology, both these sonifications establish relationships between separate moments in time. Further, instead of following on each other through simple and unidirectional causality, these moments are thought to be connected through intricate political, economic, and/or social factors. In this sense, they can both potentially serve as strategies one can employ when wanting to take into account Druckerian critiques of linear timelines. However, when compared with de Campo and Dayé, *The Locust Wrath* makes use of a more complex and multilayered temporality, and its creation is dependent on a greater degree of artistic agency. While *Navegar É Preciso* is designed to problematize ideas regarding historical progress, it also makes use of a rather traditional sonification strategy of directly mapping data onto sound. For example, the movement through geographical space is expressed through movement in time, where one kilometer on a map is represented as a certain duration of time in the sonification. Further, values in the data are directly audible. For instance, the higher the value of the parameter GDP, the higher the pitch of a certain sound. In *The Locust Wrath*, data is expressed in a much more intricate manner. While the project made extensive use of direct parameter mapping, the resulting sounds where further elaborated from a musical perspective. This was partly necessitated by the use of acoustical instruments as part of the performance, but also by the need for the sonification to make sense as music, both for the dancers and for the audience. According to Lindborg (2018, p. 470), the sonification designs had to be heard as "convincing and poetic", making use of the meaning-making potentials of sound. In order to realize this, sounds and their qualities where used as metaphors. Lindborg describes an example of this, using acoustic instruments during the live performance: "If there was rainfall in a geographical area on a certain day, a specific string was struck at the corresponding time in the piece. If it happened to be hot that day, the string resonated longer, and in addition, high humidity gave it a deeper vibrato." (p. 471)

As we can see, information is here not only expressed through musical sounds, but also by referencing sounds found in the non-designed, natural sonic environments that humans inhabit (a similar approach named "musical mimicking" is propagated by Quinton et al., 2018). According to Lindborg (2018, p. 473), “good principles for successful aesthetic sonification” can be found in the experience of such environments, which further implies that sonification should embrace soundscape research as well as music. Taken together, *The Locust Wrath* is presented as a deliberate move away from the “scientifically biased” (p. 473) perspectives that have been prominent in the field of sonification. Interestingly, it instead makes explicit use of insights drawn from the two perspectives highlighted in this chapter as especially relevant to humanistic sonification: embodied cognition, with its focus on meaning-making through sound, and the phenomenological approach, expressed through theories of listening modes. This means that the sonification is not designed with passive receivers of information in mind, but for listeners perceived as active parties in the creation of meaning. One way of making sense of this approach is perhaps found in the critical hermeneutics of Drucker (2020, p. 45), according to which, as we have seen, every “text” (which can be a visualization or a sonification) is understood as a “field of possibilities”. When a reader approaches the text, it is a co-creator, intervening in the field and actualizing one out of many possible meanings. In *The Locust Wrath*, it is not only the audience that “reads” the data in this way, but also the dancers and the composer, collectively making the data-expressed-as-sound mean something.

7 Sonification Design

This chapter describes the tools and data used for creating the sonification prototype, as well as the reasoning behind individual design choices and behind the overall conception of the design. The data set used – extracted from the Spotify platform – can be described as being of a musical-historical and musicological nature. A direct reason for this musical focus is that the author of this thesis has some background within musicology and within (hobby) electronic music creation. This background also explains the use of the rather intricate tool of SuperCollider, of which the author has some previous knowledge.

7.1 Spotify data set

The Spotify data set is used as a basis for the sonification prototype. The data in the set has been extracted from a total of 169,910 sound files or tracks recorded during the years 1921–2020, as available in the Spotify database. The data was retrieved and tabulated through the Spotify Web API by the Turkish data scientist Yamaç Eren Ay and it was downloaded from Minamedez (2020). While mostly music of all types and genres, a number of sound files also contain recordings of speech (radio shows, podcasts, poetry readings, etc.). For each track, a Spotify ID, artist name, and name of piece is given, as well as release year and track duration. Further, the following audio features are defined. Most of these attributes are defined as a numerical (floating point) value ranging from 0.0 to 1.0 (Dola, 2021; Minamedez, 2020; Spotify, n.d.).

Acousticness. Measures confidence whether the track is acoustic or not. A value of 1 means high confidence.

Danceability. Describes how suitable the track is for dancing, based on a combination of musical elements such as tempo, rhythm stability, beat strength, and overall regularity.

Energy. Represents "a perceptual measure of intensity and activity". Tracks with high value feels "fast, loud and noisy" (Spotify, n.d.). The measure is based on attributes such as loudness, timbre, and dynamic range.

Instrumentalness. Predicts whether a track contains vocals or not. A value of 0.5 means that the track is instrumental, but the confidence increases when approaching 1.

Key. Extracts the main key of the track as represented by an integer value ranging from 0–11, where 0=C, 1=C#/Db, etc. A value of -1 signals that the main key is unclear.

Liveness. Detects audience noises signaling that the track was recorded in a live setting. A value over 0.8 means a high probability of a being a live recording.

Loudness. The average loudness of the track measured in decibels (dB). Values generally range between -60 and 0.

Mode. Analyses whether the track is mainly in the major or minor mode, based on the type of scale that the main melodic material is based on. An integer value where 0 is major and 1 is minor.

Popularity. A value between 0 and 100 based mainly on the number of plays the track has in Spotify.

Speechiness. Detects the presence of spoken words in a track. According to Spotify (n.d.), a value above 0.66 signals that the track is most likely not music, while values between 0.33 and 0.66 means that the track contains both speech and music, either layered or segmented. Consequently, tracks within this range should mainly either be radio programs or rap music, but there is no way of distinguishing them using this measurement.

Tempo. The overall tempo of the track in Beats Per Minute (BPM).

Valence. Describes the "musical positiveness conveyed by the track". Tracks with high value "sound more positive (e.g. happy, cheerful, euphoric)", while a low value signals music that is "sad, depressed, angry" (Spotify, n.d.).

As can be seen, the set contains a number of fundamental and unambiguous variables, describing the artist, title, year, and duration of each track. Apart from this, it also contains a range of variables which quantify the musical characteristics of each track. Some of these are quite straightforward, such as tempo measured in beats per minute (BPM), key (e.g., D or F-sharp), and mode (minor or major). Other variables represent a more complex interpretation of the musical material, quantifying characteristics such as "danceability", "instrumentalness", and "valence".

These data have been gathered through machine learning systems for analysis and characterization of large sets of music. The systems were originally developed by Echo Nest, a software company owned by Spotify since 2014. It is used for automated music classification, genre categorization, and personalized music recommendations (Krogh, 2020; Prey, 2018). Clearly, data such as these are not generated for the purpose of academic research, especially not for interpretative research within the humanities. Nevertheless, the data can be said to cover a subject area – musical history – studied within the humanities. It constitutes a cultural record, albeit generated in a form useful for a platform such as Spotify. Going back to the definition of humanities data given in subchapter 4.2 – that it should either be produced as a result of humanities scholarship or cover a subject area relevant to the humanities – the data set qualifies as relevant for the design of the sonification prototype. It is rather common that humanist scholars have to rely on records that are not intended for scholarship. In a discussion of the practical and theoretical aspects of data within the humanities, Borgman (2009) points out that such data rarely are produced through experiments or observations. Instead, records are the most common source for data in the (digital) humanities. In such cases, humanities scholars have to work with whatever form the records come in, repurposing them to align them with the aims of the research at hand.

In order to achieve such alignment, one must – from the outset – be clear about the limitations inherent in the data. In the case of the Spotify data set, one important limitation is rooted in the fact that it has been constructed through the subsumption of a piece of the cultural record under a unified system of measurement, imposing a number of standardized metrics on what are fundamentally qualitative aspects of the music. This is obviously true regarding quantified characteristics such as *Valence*, but even seemingly clear-cut parameters such as *Tempo* or *Key* can often be ambiguous: a piece of music might go through a number of tempo changes and its main key can be a matter of interpretation. Nevertheless, through the data set distant readings of large scale musical trends, correlations, and relationships, not least over time, become possible. Further, it is precisely because the data set quantifies aspects of music that can be considered unquantifiable that it potentially provides fertile ground for identifying ambiguities, allowing for a multitude of interpretative possibilities. Finally, it also needs to be mentioned that while there exist a number of visualization and exploratory analyses of this Spotify data set (Dola, 2021; Hsieh et al., 2021; parasbisht126, 2021), it has not been sonified before. This makes the sonification prototype design an interesting first.

Regarding the overall characteristics of the data set, it must be asked whether the use of large-scale data derived from a music streaming platform – of "big cultural data" (Manovich, 2016, p. 9) – situates this thesis and its data perceptualization experiment within the realm of cultural analytics. Cultural analytics can be understood as a niche field related to the digital humanities. According to Manovich (2016, p. 1), the field comprises "the analysis of massive cultural datasets and flows using computational and visualization techniques". Manovich further defines cultural analytics as involving the use of methodologies and goals drawn from both the humanities and computer science, without choosing between the two, and without subordinating one to the other. When compared to this, the present thesis is much more firmly grounded in humanistic approaches through its perspective of critical hermeneutics, thereby subordinating the quantitative and computational methods made use of (noting as well that Drucker holds a rather critical view of cultural analytics, or at least of parts of Manovich's work, see Drucker & Bishop, 2019). The ambition is to try to apply this perspective on the process of sonifying the Spotify data set. Further, cultural analytics overwhelmingly makes use of visual modes of perceptualization and analysis, having yet to include sonification in its methodological repertoire (a search on the Cultural Analytics journal webpage using the terms "sonification", "auditory display", or "audification" yields 0 results). However, this does not mean that it is not possible to find common ground with cultural analytics. If nothing else, the sonification of the Spotify data does seem to have things in common with the practice of "media visualization", which according to Manovich "involves translating a set of images into a new image that can reveal patterns in the set. In short, *pictures are translated into pictures*" (Manovich, 2020, p. 215) (italics in original). Clearly, something similar is attempted through the prototype design in this thesis: to translate a data set based on audio into new audio; to translate sound into sound.

7.2 SuperCollider audio programming language

The SuperCollider audio programming language is the only tool used in the thesis for rendering data into sound and designing the sonification prototype. The choice of creating an original piece of code rather than simply using an existing software solution was a deliberate one. Clearly, coding is a skill that takes time to develop, and the use of code puts complex demands on researchers as well as the peers that are reviewing the research. At the same time, code brings a number of benefits. As we have seen, the field of sonification – just as the field of data visualization – is dominated by perspectives derived from engineering and the natural sciences. Taking into account the cautious approach advocated by Drucker and others when importing tools from these fields, the idea is that a programming language will carry much less of a methodological and epistemological "baggage". This argument is made by van Zundert et al. (2020), as well as by Arnold and Tilton (2019). The latter argue that it is possible through code to avoid "privileging preconceived notations" (Arnold & Tilton, 2019, para. 12), and to instead explore and potentially invent methods of working with data that are adequate for the (digital) humanities. Van Zundert et al. makes the further point that coding is especially useful when there is a need to "explore and examine new tools and techniques" (2020, p. 135). Finally, Montfort (2016a) makes a similar point when he frames programming as a way of thinking and inventing rather than simply as a technical skill or a task that can be delegated to others.

More specifically, as a general-purpose audio programming language, SuperCollider affords a range of possibilities when working with a data set such as the one explored in this thesis. On a technical level, SuperCollider is divided between two components according to a server-client model. The server – called *scsynth* – is basically a synthesizer that is controlled by the client – named *sclang* – the actual programming language. Consequently, a data set, for instance in a .csv format, can easily be imported into SuperCollider and be made to directly control any sound generating parameter. Further, real-time manipulation is possible. This means that the sound being generated is changed instantaneously when editing the code, which makes SuperCollider ideal for the practice of exploratory programming. Finally, and importantly, SuperCollider is open source, which makes it freely available for anyone caring to read this thesis. The code can therefore be tested without having to go through any proprietary software (or without having any coding skills, since the code can be copy-pasted into SuperCollider and executed following a few simple instructions).

7.3 Design conception and strategy

In the literature surveyed for this thesis, there are no examples of sonifications that are based on a similar type of data set as the Spotify set. This means that the sonification design have had to be invented "from the ground up", involving experimentation with various design ideas through exploratory programming. However, the process has also involved a continuous dialogue with the literature, drawing on other sonification designs and on critical discussions on methodology. Further, the overall and most basic characteristics of the sonification had to be decided from the start. For one thing – as was made clear in the subchapter on delimitation under Methodology – the thesis is to focus on the purely sonic elements of sonification, avoiding its potential multimodal and interactive aspects. Consequently, the sonification design is of purely sound-based nature and it allows only for the most minimal degree of interaction on behalf of the listener. This basically means that possible interactions are limited to simple playback, which can be started, paused, or stopped.

It was also decided from the start that the sonification design would make heavy use of musical features. As was made clear by the argument made in the extended review, musical sonification, or at least the inclusion of musical components in sonification, should be considered a plausible method for the perceptualization of at least some types of humanities data. Therefore, on a general level, the aim of the sonification design is to express or interpret various dimensions of the data set using musical elements. This is partly achieved through a process of mimicking, similar to, and drawing inspiration from, design ideas described by Quinton et al. (2018). They describe a process of musical mimicking through which an arbitrarily chosen sound is not simply meant to represent a given characteristic in the data. Instead, it is made to sound alike the phenomenon it is referring to (for instance, a sonification of rainfall data being made to sound like rain). This approach has similarities with the manner sonic metaphors are used in *The Locust Wrath*, described in chapter 6 above (Lindborg, 2018). In the present sonification design, the characteristics mimicked are inherently musical. For example, the idea is that a high value of *Danceability* is "mimicked" by making the sonification easier to dance to; a high value of *Energy* by making its mode of expression more energetic, and so on. Needless to say, since the audio features are ambiguous, the kind of mimicking attempted here inevitably involves a great deal of interpretative work.

As was seen in several of the sonification examples, and perhaps especially in the sonification created for *The Locust Wrath*, the design of musical sonification means striking a balance between the expression of musical ideas and the successful communication of patterns within sets of data. Further, one recurring mode of critique against musical sonification was that the need to stay faithful to the data would mean severely constraining the creative freedom of the designer/composer, resulting in music that is less aesthetically pleasing (Devroop & Titlestad, 2021; Vickers, 2017). While this might be true, the incorporation of music in sonification means that the designer is granted quite a large degree of freedom, given that there is no standardized and/or widely accepted method of design. In the present sonification, this dilemma was tackled by attempting to strike a balance between the use of musical elements – the kind of musical "mimicking" described above – and a more direct approach using parametric data mapping. Parameter mapping means that data dimensions are allowed to directly manipulate sound parameters (Hermann, 2008). According to Worrall (2019, p. 38), data dimensions are mapped "either to physical (frequency, amplitude), psychophysical (pitch, loudness) or perceptually coherent complexes (timbre, rhythm)." Worrall further mentions a number of benefits of this approach. First, it allows for the simultaneous presentation of several parameters. It also makes possible a flexible approach in which it is easy to change and fine-tune mappings during the design process. Finally, parameter mapping is well suited for the electronic music tools often used for sonification. Consequently, it is possible to argue that parameter mapping is an effective method when working with an exploratory programming approach using a tool such as SuperCollider.

Given that parameter mapping is a well-established method for sonification, and given that it allows for some degree of formalization, a further benefit is that it becomes possible to draw on the diverse methodological material found in the literature. One such methodological suggestion regards the amount of parameters that a listener can reasonably be expected to perceive in a non-interactive sonification (see for instance (de Campo, 2009, 2007; Flowers, 2005). The total amount of parameters available in the data set should generally be considered to be too many, which is why only half (6 out of 12) of the available musical attributes are used. These are: *Danceability*, *Energy*, *Key*, *Mode*, *Tempo*, and *Valence*. There are various reasons behind choosing to include these specific attributes. The attributes of Loudness and Popularity were deemed less interesting. Loudness simply represent the overall volume levels of the recorded music in the data set, mostly reflecting production methods during various points in time. As for Popularity, this value only reflects the number of streams a given piece of music gets today, not for instance record sales when it was released. Further, Spotify includes how recent streams are into this metric (Hsieh et al., 2021). Regarding the parameters Speechiness, Instrumentalness, Liveness, and Acousticness, these are musical elements that can clearly be of interest to follow over time. However, they are hard to mimic within the confines of the chosen musical genre (this goes for Popularity as well). Further, they are also elements that are hard to mimic using only electronic sound synthesis. For instance, mimicking speech, the singing voice, or acoustic instrumentation requires very advanced sound synthesis methods, and would also need to make use of a substantial amount of computing power. It would not have been realistic to include such elements in this thesis.

As was pointed out above, the combination of direct parameter mapping with musical sonification should be seen as a compromise or a balancing act, made necessary by the scope of the thesis. It also needs to be mentioned that parameter mapping can be considered problematic when understood through the Druckerian theoretical framework of the thesis, especially when combined with a linear timeline. With Drucker, it would be possible to argue that the direct and singular representation of data dimensions inherent in parameter mapping would constitute an authoritative statement, an “it is” rather than a “what if”. As such, it would serve to hide the interpretative work that is necessary for all forms of sonification design. It is worth noting that a similar critique can be found in parts of the sonification community. Worrall (2019, p. 128), for instance, argues that an emphasis on “...parametric sonification is, in general, [...] somewhat in alignment with positivist thinking.” It should be made clear that parameter mapping is used here despite these valid points of criticism. If anything, this points to the difficulty of overcoming such rather convenient approaches to sonification, especially given the limited scope that the present sonification is given within the thesis as a whole. This, however, will be discussed in more detail under Discussion in the concluding part of the thesis.

In any case, these limitations are, at least in part, meant to be counteracted through the use of two compositional strategies in the sonification design. One drawback with parameter mapping is that it will tend to produce rather abrupt changes as the sonification moves through the data. The first strategy therefore involves the choice of a style of music which makes such changes more smooth. This, in turn, is meant to make the sonification more musical, and less directly dependent on exact values in the data. The second strategy makes use of a certain degree of randomness, making each playback of the sonification different by making the occurrence of certain sounds dependent on chance (however, this only works when playing the sonification through SuperCollider, not when one is listening to a sound file containing a recorded version of the sonification). For Drucker, a problem arises when only one representation of a pattern within data is visible, when it appears to be set in stone. As an alternative, she advocates an approach through which different aspects of the data becomes perceivable every time one returns to a visualization. By "altering any single factor in the model", she argues, it is shown "that a different sample would be produced": "This simple move immediately shows that the data produced by any model is only an expression of that model and that the visualization is of the data model, not the phenomenon from which it was extracted." (Drucker, 2020, p. 54)

7.4 Design implementation and sonification description

The sounds of the sonification are exclusively generated using the SuperCollider synth, making no use of samples or external sound sources. This means that the sonification can be played back using only the SuperCollider code – which can be found in Appendix 3 – making it easy to reproduce. Given that the sounds have been programmed from scratch, they can generally be characterized as quite simple. Genre-wise, the sonification can be described as a stripped-down and rather elementary techno or electronic music piece. At its center is found a simple rhythmic structure: a steady beat as highlighted by a layer of percussive sounds. Each year of data is represented by four beats of music, each beat being accentuated by a hit with the kick drum and every second beat by a snare drum. Given that the overall tempo of the piece fluctuates between around 100–120 Beats Per Minute (BPM), each year is represented by 2–2.4 seconds of music. This means that the whole piece has a duration of around 3 ½ minutes. Sound-wise, the piece is comprised of three distinct sonic layers: a bassline, a set of percussive sounds, and a repeated chord. The percussive layer consists of a kick drum, open and closed hi hats, and a snare drum (these percussive sounds were created borrowing heavily from (Rumblesan, 2010)).

With the exception of *Key*, the data was prepared through calculating the average value for each year. It is this average value that is the basis for the generation of sound, and that is thus "played" by the sonification. With *Key*, only twelve values are possible. Therefore, rather than an average, the most common key for each year is calculated. Another special case is the *Mode* value. Since a quick overview made clear that the major mode is the most popular mode for every single year that is represented in the data, an approach was chosen that calculates how common the two modes where in relation to each other for each year. This resulted in a value between 0 and 1, where for instance 0.75 means that the major mode was used in 75% of the songs and minor in the rest, while 0.25 would mean that it was used in 25% of cases, and so on.

A few parameters are mapped in a direct and fairly obvious manner. The representation of each year in the data by four beats/bars of music means that the time flows forward in a linear manner. Further, the **Tempo** value is mapped directly onto the tempo of the piece, meaning that the sonification is played in accordance with the average BPM for each year. However, in order to avoid abrupt changes in tempo between years, the BPM changes very gradually, transitioning between values in a smooth manner. The aim here was to make the piece more musically pleasing. This means that changes in tempo in the data only becomes visible (or "hearable", rather) in the form of long time trends. Finally, as for **Key** for each year, the value is mapped directly onto the bassline, which plays the root note of the most popular key for each year. In a similar manner, the most popular key is also played by the chord layer, in the form of simple triad chord. Here, however, in order to avoid constant and abrupt chord changes between individual years, a chord change only takes place if a specific key is the most popular one for at least three years in a row. Once again, the aim with this particular design choice was to make the piece more appealing.

In contrast, a much more complex process of correlating sound to data is implemented in relation to the musical attributes of *Energy*, *Danceability*, *Valence,* and *Mode*. Instead of letting these qualities be represented by single and easily recognizable sound attributes, they are expressed through a combination of sonic patterns and events. In the case of *Energy*, elements of randomness are also included.

For **Danceability**, a simple form of direct mapping on the percussive layer is combined with more subtle forms of manipulation of the bass line. The volume of the percussive layer is dependent on the value for *Danceability*: the higher the value, the louder the percussion. At the same time, the characteristics of the bass line is correlated with *Danceability*, the bass line becoming more pronounced with higher values. This is achieved by lowering the attack and release time for the bass notes, both for volume and for the low-pass filter that is used on top of the bass synth. This means that when *Danceability* is low, the bass notes tend to overlap each other, making them more softened and muted, and therefore overall less distinguishable. Vice versa, when *Danceability* is high, the bass notes are more distinct, giving more "drive" to the bass line, giving it more of a percussive quality.

For **Energy**, the general idea is that the higher the value, the more energetic the music becomes. This is achieved through manipulation of the percussion and chord layers. For the percussion, there is a certain chance of extra hits with the kick drum, snare drum, and hi hats. With a higher value of *Energy*, this chance increases, generally causing a thicker and more intense percussive layer. For the chord layer, higher *Energy* results in a sound that is more harmonically rich, while lower values makes the sound softer and more muffled. This effect is accomplished using a simple low-pass cutoff filter which allows for higher frequencies with higher

Energy. The resonance value of the filter is also correlated to *Energy*, with sharper resonances being caused by higher values.

For **Valence**, its value affects the characteristics of the sound of the chord layer. This audio attribute is perhaps the most ambiguous of the ones used in the sonification, given that it is meant to reflect the emotional content or character of the music. In the sonification, lower *Valence* values, ostensibly representing music that is “sad, depressed, angry”, is interpreted as *dissonance*. Vice versa, higher values, reflecting musical content that is “happy, cheerful, euphoric” (Spotify, n.d.), are expressed through the use of (musical, harmonic) *consonance*. In practice, the *Valence* value is translated into a detuning of the synth chord: with high values, the main chord is more harmonious, while a lower value adds dissonance to it.

Finally, **Mode** is mapped directly onto the main chord layer. In this layer, the synth plays two chords: first, a major chord in the most popular key of the present year. Two beats later, this chord is followed by the parallel minor (e.g., C major followed by A minor). The *Mode* value decides the relative volume for each of these chords. For instance, for a year where major is the main mode for 75% of the songs, the volume of the minor chord is one third of that of the major chord. Both the chords have a rather long duration (in total 2.3 seconds). This design decision is based on the assumption that a listener will encounter the chords not simply as two separate musical events, but as overlapping each other, fusing them. The idea is that the listener will experience the chord layer as a continuous harmonic flow rather than distinct chords, in which the relative volume of the two chords will be experienced as degrees of “major-ness” and “minor-ness”.

8 User study

The user study was announced on the Facebook SuperCollider forum on 25 October 2022. A link to the online questionnaire was sent to individuals expressing an interest in participating through the Facebook private message function. The link was also shared on a mailing list used by academics with an interest in issues regarding music and technology. The survey was closed on 13 November 2022. In the end, five people participated and submitted replies to all nine questions in the questionnaire. For practical reason, the respondents were only provided with a recording of the sonification and not with the SuperCollider code itself. This meant that the random elements that are an integral part of the sonification were not discernible for the respondents. This is to be considered a limitation in the user study that is to be taken into account when evaluating it.

8.1 Survey overview

The nine questions in the questionnaire – which can be found in full in the Appendix – were clustered around a few overarching themes. To begin with, the respondents were asked to say something about their professional or academic background and previous experiences, especially in relation, if existent, to the field and practice of sonification. The rest of the questionnaire was dedicated to how the sonification was experienced and interpreted by the respondents. Importantly, as a main thrust of the survey, this involved a number of questions focusing on whether the design of the sonification allows one to sense or read (if this visually oriented metaphor is tolerated here) the data. The respondents were asked if it is possible to identify individual data trends through their sonic expressions, and whether some trends were easier to follow than others. Related to this, a question regarding the ability of the respondents to follow trends over longer periods of time was also asked. Apart from this focus on the individual mappings of data to sound, the respondents were also asked to elaborate their views on whether the overall idea and design of the sonification made sense, and what practical applications they saw possible. They were also asked to suggest different design ideas, if they had any. As the closing section of the survey, the respondents were encouraged to reflect on the aesthetic qualities of the sonification. They were asked if they consider it music, and if they like or dislike it on purely aesthetic grounds.

8.2 Background, areas of expertise, and experience of respondents

All respondents reported being involved in music in some way, as musicians and/or in music as an academic field of study. In some cases, this was reported as being on a professional level, with respondents dealing with music, for instance in the capacity as composers or researchers. In other, music was described as a hobby. Overall, most respondents describe a focus on, and an interest in, electronic music composition. These traits were to be expected, given the forums used for recruiting the respondents. It was also something aimed for since an understanding of the data set used in the sonification requires at least some prior knowledge of musical-theoretical concepts, as well as some basic principles of electronic music composition. As for previous experience or knowledge of the field and practice of sonification, it varied a great deal between respondents. One respondent reported never having come across it, while another one described being presently engaged in a research project involving advanced data sonification. The other respondents reported prior knowledge somewhere in between these two extremes, having read about it or come across it at conferences. One respondent had been a part of a panel discussion partly revolving around the subject of sonification.

8.3 Respondent evaluation and experience of the sonification

Many of the responses received touched upon some of the key issues of sonification discussed in the extended literature review, and especially the issue of how sonification relates to art and music. Drawing on Drucker, it can be argued that the implementation of (fine) arts and aesthetics is a central concern in any form of data perceptualization. For instance, when answering questions regarding possible applications for the sonification (questions 3 and 7), most respondents acknowledged its potential use from a utilitarian perspective, as a means for reading and interpreting the data (for instance for the categorization of music styles). At the same time, respondents tended to emphasize a different aspect of the sonification: the sonification of data as a creative strategy, as a means for finding novel ways of composing music or sound art. For example, one respondent writes that the sonification could provide "jumping off points for musical creativity that you might not have otherwise found". Another respondent discusses the "probably mythical" possibility of finding a perfect balance between, on the one hand, using the sonification for revealing trends or structures in the data, and on the other, experiencing the sonification as music that is pleasing and/or interesting in its own right. Clearly, while the number of respondents is much too small for drawing any general conclusions, it is likely that this focus on the creative aspects of sonification reflects the fact that all respondents are in some manner or another musicians. That people that take an interest in sonification are also involved with music is, as we saw in the extended literature review, quite common within the sonification community at large.

As for questions dealing with the ability of identifying individual features and following trends in the data over time (questions 4–6), most respondents asserted that they were able to do so in relation to at least some audio features. The only exception in this case was the respondent that reported having no previous experience of sonification in general, who had difficulties following any of the trends. As was perhaps to be expected, given the design choice of mapping *Tempo* directly onto the BPM of the sonification, many respondents found this audio feature easy to distinguish. They were also able to identify the long term trend of an increasing BPM. Further, some respondents reported that the audio feature *Key* – another example of direct mapping within the sonification – was uncomplicated to follow.

However, within the context of the overarching theoretical aim of this thesis, the replies received with regards to the less straightforwardly mapped audio features are perhaps of greater interest. A gradual increase in tempo in a piece of music is generally easy to sense for most people, but what about the more ephemeral qualities of "danceability" and "energy"? One respondent reported that the sonification "felt more energetic towards the end", while another experienced an increase of both *Energy* and *Danceability* over time. At the same time, one respondent reported that these two particular features were hard to tell apart. Given that one of the key aims of the sonification design was to facilitate for users to *experience* or, using the vocabulary of Neuhoff (2019), *sense* rather than to simply successfully *read* or *identify* audio features, these replies perhaps point to some degree of success. Rather than a simple reflection, the music-sonification is meant to present itself as an interpretation of the data. Therefore, it is not necessarily a problem that users have a hard time distinguishing between *Energy* and *Danceability*, or that these features seem ambiguous in relation to each other. As one respondent points out, these two features seem closely related to tempo in that higher values *in combination* (more percussive sounds, more intense and rich timbre, and a higher BPM) seem to generate music that is experienced as more danceable and energetic.

Some replies, especially given in relation to question 8, put forward suggestions for possible different approaches for the sonification design, both on the level of individual mappings and regarding the overall design conception. Regarding mappings, two respondents suggest using more distinctive sounds, timbres, and/or "instruments" for making individual data lines more easily perceptible. As for the overall design, two responses discuss the genre of music chosen, arguing that its culturally specific form risks bringing a baggage of preconceived notions, thereby limiting the possible ways of engaging with the sonification. For instance, one of these two respondents states being "a bit put off by the fact that the whole thing sounds like music made in late 20th C early 21st", since this meant that this particular style of music was used to "represent music over the whole 100 year period". Instead, the respondent suggests as an example that "honky tonk" could have been used for representing the early 20th century. As we saw in the extended literature review, the fact that musical forms of expression are culturally and chronologically situated has made parts of the sonification community doubt their usefulness in the context of sonification design (Vickers & Hogg, 2006; Worrall, 2019). Drawing on this particular answer, at least, this user study validates this concern. However, the same respondent also suggests a design approach that might allow one to escape this limitation, suggesting making the music "more abstract" since this might "disrupt that desire for a simple mapping between period and style". Again, this is a theme encountered in the review as well, for instance through the suggestion by Vickers and Hogg (2006) of applying musical forms drawn from electro-acoustic composition to sonification. By avoiding well-known types of music, they argue, listeners might become more inclined to approach the sonic material and the data it is meant to reflect or express with fewer preconceptions.

The final question of the questionnaire is dedicated to the aesthetic dimensions of the sonification, interrogating, among other things, whether respondents experience any musical qualities. While most respondents actually felt the piece could arguably be considered music, most of them found it less convincing as an aesthetic artifact.

Music, but not necessarily good music, in other words. For instance, in one reply, it was argued that the piece did not progress, but rather appeared to be “constantly struggling”. Another reply described it as lacking “convincing structure” and as generally unappealing. One respondent – probably the most critical one – stated having preferred simply looking at a graph instead. On the other hand, another respondent found it “interesting” as a stand-alone piece of music, describing it as “harmonious” and “pleasing”, which, according to the respondent, sets it apart from many other examples of computer-generated music. This one rather enthusiastic respondent notwithstanding, the critical manner in which the sonification was received can be said to reflect a general issue with the “genre” of musical sonification, which was also encountered in the extended literature review. As was argued by for instance Vickers (2017), there is a contradiction between the purely aesthetic aim of musical composition and the communicative, data-driven purpose of sonification. There is always the risk of this latter purpose outweighing any musical considerations, leading to the creation of an impoverished and not very engaging composition from a musical perspective. On the other hand, it does not seem unlikely that the fact that the respondents generally can be described as musically literate makes them more critical when assessing the aesthetic and musical qualities of the sonification. More than one respondent also expressed an understanding for the fact that the research- and data-driven nature and aims of the sonification will tend to limit its purely musical merits.

As a closing part of this chapter, it is possible, using the answers given in the questionnaire, to reflect on the way data is expressed or reflected through the sonification, on an overarching level. One respondent briefly discusses, in a critical manner, the way in which the sonification is designed to highlight certain aspects of the Spotify data, while concealing others, thereby facilitating one type of interpretation or reading. During the design process, the data was prepared by finding the average or most common values for each of the audio features for each year. These values are then used for regulating the generated sounds, meaning that the sonification reflects the most mainstream music. The respondent suggests that it might be more interesting to try to sonify the data in a manner that allows one to find marginalized types of music, that is, checking the “opposite trend”, asking “what kind of music is the less listened to and why?”. The respondent gives the following possible examples of such music: “Free music, improvised music, harsh noise or extreme music, field recordings ... opposed to pop, hiphop/rap, dance, etc.” Such sonification projects aiming at expressing and interpreting the features of music at the margins would of course require a radical rethinking and redesign of the sonification presented in this thesis, perhaps also making use of a different genre of music as the vehicle of the sounds. At the same time, a sonification project of this type might be more in line with a Druckerian approach to data perceptualization. As we have seen, for Drucker, it is crucial that computational tools produce results that leave room for a multitude of perspectives, especially when dealing with historic data arranged within timelines. Relying on averages and most common values will always risk pushing one single perspective, even though there is no single way of correctly reading the sonification. Trying to make room for alternative, more narrow, and less popular types of music, perhaps arranged as contrasting layers on many different timelines, might be one way of avoiding the reliance on a too narrow of a perspective on the data. This, in turn, might further highlight the contradictory and ambiguous nature of the material, allowing for comparisons and a deeper interpretative engagement.

9 Discussion

On the most general level, this thesis has found that sonification remains largely unexplored as a method for perceptualizing data (or, perhaps, "capta") within the digital humanities. This was confirmed already in the chapter on previous research, but was also an important finding of the extended literature review. Within the field of sonification research and design, discussions of the implementation of sonification in humanities disciplines, or of sonification based on humanities data, are mostly – but not entirely – absent. In this thesis, it is argued that this is to be perceived as a problematic lack since sonification as a method opens up a range of interesting possibilities in relation to the challenges specific to digital humanities data perceptualization. That is, there are a number of theoretical and methodological viewpoints within the field of sonification that are relevant for the (digital) humanities, and the use of sonification on humanities data has the potential of allowing for the discovery of new perspectives. While the three research questions presented in the introduction to this thesis obviously are not of a "yes" or "no" character, this nevertheless means that positive answers can be given to them. Further, it also means that the purpose and aims of the thesis have been successfully achieved.

It can be useful here to reiterate the purpose, aims, and research questions. The overall aim of the thesis was described as to provide both a theoretical and practical early-stage exploration of sonification as a method for the digital humanities. The research questions further specified this aim by staking out three closely interrelated areas of investigation, asking: first, if there are theoretical and methodological perspectives within the wider field of sonification that can be applied when dealing with humanities data; second, if these perspectives can be aligned with the interpretative thrust of the critical hermeneutics of Johanna Drucker; third, if, and in what way, sonification can be used for enriching the possibilities for interpreting data within the digital humanities. While these questions cannot be answered separately, the first two questions were nevertheless directed more towards the theoretical portion of the thesis, while the third was, at least partly, aimed at interrogating the sonification design through an evaluation of the sonification of the Spotify data set.

The extended literature review carried out in chapter 6 has already highlighted a number of theoretical and methodological outlooks that are potentially of relevance for the (digital) humanities, and it has shown how these perspectives have much in common with Drucker's theoretical framework. There is no need to repeat these findings here. Rather, here is the place for drawing this discussion further, allowing for a certain degree of speculation, and also for synthesizing the findings of the various chapters. Nevertheless, summarizing the most important findings, the review has made clear that sonification cannot be understood as a unified field, but that it is – increasingly – comprised of a range of different disciplines. As a result, existing sonification projects make use of a wealth of often contrasting theoretical and methodological frameworks. While some might view this state of affairs as a lack or as a sign of a field still in its infancy, one may also argue that it allows one to arrive at sonification from many distinct epistemological points of departure. For the digital humanities, the review focused on perspectives that ascribe sound with capacities beyond the simple transmission of information. For instance, discussions of embodied cognition were highlighted due to its focus on the meaning-making capacities of sound. Further, attention was directed at the phenomenology of listening, given its recognition that the experience of sound is complex, multi-layered and difficult to quantify without losing intrinsic meaning.

At the same time, there are aspects of sonification that are missing in the review, and that would stand in need of further in-depth elaborations. This is perhaps especially true regarding discussions on the affordances of the medium of sound. The theories discussed mostly focus on the listener, and not on the sounds in themselves. While sounds clearly cannot be studied outside a socio-historic context – which is embodied by the listener – they also carry distinct potentials when compared with textual or visual modalities. What these potentials are is far from a trivial question. In the thesis, musical sounds – in itself not an easy concept to define! – end up becoming an important focus. It is argued that the nature of such sounds, which require aesthetic choices by the designer, highlight sonification as interpretation rather than simple representation. As such, musical sounds have the potential of achieving the *modeling of interpretation* advocated by Drucker. This, at least, perhaps form one part of the wider question of the affordances of sound.

Regarding the question of whether sonification would be better suited for data perceptualization within the digital humanities simply through its use of sound – that is, if sound in itself would be more appropriate than say visual modalities – the answer given through the review would probably be no. As we saw, the type of sounds used are very much dependent on the general purpose of the sonification design. Designs that take aim at unambiguously transmitting information usually make use of the simplest of sounds, arranged in temporal structures that are linear and easily recognizable. At the other end of the spectrum, sonifications with meaning-making ambitions, which aim at incorporating ambiguities and a multitude of possible interpretations, will tend to be more complex on every level, implementing multi-faceted arrangements of sounds. If sonification is to be applied as a method within the (digital) humanities, it needs to make use of (or invent!) design methodologies that are fitting to the specific challenges of humanistic disciplines. In any case, the affordances of sound for communicating and interpreting humanities data, as a specific and separate question, provide one possible trajectory for potential future research on humanistic sonification.

From the outset, the thesis was conceived as divided into two overarching parts: one theoretical, focusing on the literature on sonification, as reiterated above, and one more practical, involving the design and evaluation of a sonification prototype. The idea was that the second part would follow in an organic manner from the first, drawing on the findings of the review. However, a critical eye might detect a certain lack of continuity between the two parts. One important reason for this is that the review was unable to locate any previous sonification projects similar to the one attempted in the thesis: a sonification of a large-scale musical-historical data set drawn from an online streaming service, aiming, at least in part, to implement an interpretative design. This meant that the design – in many of its aspects – had to be invented from the ground up by the use of exploratory programming (a type of programming that is one of the explicitly stated methods used in the thesis). At the same time, the design did make use of some of the findings of the review, especially on the abstract and theoretical level. For one thing, the idea of creating a specifically *musical* sonification is well grounded in the review, as was the attempt at creating a sonification complex enough to require repeated listening. Using the vocabulary of Pierre Schaeffer's phenomenology of listening, the sonification would need to be *heard* and to perhaps to some degree *understood*, not simply *perceived*.

Another consequence of the two-part nature of the thesis was that the sonification ended up being limited in scope, focusing only on a very small segment of the many challenges involved when perceptualizing humanities data. An extensively more ambitious sonification would probably not have been possible within the confines of a master thesis such as this one, even if the focus would have been put solely on the practicalities of sonification design. Nevertheless, the modest scope hampers the possibility of answering the third research question in a thorough manner. Clearly, judging from the results of the extended literature review, it is possible to argue that sonification does, in a variety of manners, allow for the enriching of interpretative possibilities. But what, if any, conclusions can be drawn from the sonification design and especially from its user study? Clearly, the user study ended up being rather limited in size, comprising replies from only five respondents. However, while this perhaps excludes drawing any far-reaching conclusions, the replies received did manage to illustrate – in conjunction with the literature – some of the challenges involved in the design of an interpretative sonification. As we will see below, they also pointed to some possible avenues for future research, beyond the work done in this thesis. It is also useful to remember the rather modest initial ambitions regarding the sonification prototype design, as stated under Purpose and Aims: to "inform and inspire potential future humanities sonification projects", not to draw any definitive conclusions regarding sonification within the (digital) humanities.

Part of the problem with the scope of the sonification is that it in many aspects fails to implement and realize – at least in a coherent manner – a Druckerian, interpretative approach to data perceptualization. Instead, the design can be seen as a compromise between a representative approach, directly mapping data onto sound, and an interpretative one. Using the dualistic vocabulary of Neuhoff (2019), the design can be said to simultaneously include elements of the *empirical* and the *artistic* types of sonification. For instance, the way in which the audio attributes of *Tempo* and *Key* are sonified could be described as (mainly) empirical. In these cases, the average or most common value for each year is directly and quite clearly perceivable through the sonification, even though it is not possible for a listener to know the exact value of the BPM simply by hearing the tempo of the piece. As examples of the artistic side of the sonification, one can mention the audio attributes *Danceability* and *Energy*. Here, the aim of the design is not to present values in a precise manner. According to Neuhoff, as we have seen, the goal of artistic sonifications is not exactness, but allowing the listener to "sense" relations within the data, thereby stimulating many different modes of interpretation. This way of reasoning pretty well sums up the design intention behind these particular audio attributes. However, it is also important to underline that different types of data would seem to require different approaches. The danceability of a piece of music is a subjective property, not easily quantifiable, and always a matter of interpretation, while its BPM actually can be measured (at least if the music can be assumed to have a steady beat, which is of course not always the case). This difference is also reflected through the sonification design.

The calculation of averages and the use of the most common values in the data as basis for the sonification design also merit critical discussion. With Drucker, one could argue that this creates the illusion of a musical history as one coherent trend, making audible only the characteristics of the most mainstream and common types of music. This rather limited view of musical history was also discussed by one of the respondents of the user study, who asked if it would not have been more interesting to create a sonification that highlighted marginalized forms of music. Such design would have used as its basis outliers and extreme values within the data, bracketing the big mass of values at its center. It would also probably have to be much more polyphonic, making audible several simultaneous trends. Perhaps such a design could – *pace* Drucker (Drucker & Bishop, 2019) – learn from work being done within cultural analytics, which according to Manovich (2016, p. 2) asks how computational analysis can “do justice to variability and diversity of cultural artifacts and processes, rather than focusing on the ‘typical’ and ‘most popular’?”. It is not unlikely that such a project would go against the grain of many presumptions, allowing for a greater variety of readings and thereby successfully enriching interpretative possibilities. In any case, the sonification design, as it was actually realized, tried to parry the problematic aspects of using averages by the use of probabilistic and aleatory elements, which are meant to highlight the sonification as only one of many possible narratives.

Another area which could have been explored in more depth through the sonification design relates to the representation or modeling of time and temporality. In the chapter on Theory, Drucker’s critique of the conventional timeline and its manner of representing time as “unidirectional, homogeneous, and continuous” (Drucker, 2020, p. 114) was designated as a key focus of the thesis. In the extended review, we saw examples of sonification designs that shunned linear presentations of the flow of time in favor of a temporality conceived as inherently social, relational, and heterogeneous (de Campo & Dayé, 2006; Lindborg, 2018). A discussion regarding the fundamental difference between linear clock time and musical time was also briefly touched upon (Tsuchiya & Freeman, 2018). In the sonification prototype, time flows as musical time in accordance with a beat that constantly changes. At the same time, each passing year in the data is accentuated by the use of a beat and percussive sounds, coming close to the kind of tick marks that Tsuchiya and Freeman warn against. This methodology also shares a likeness with the way conventional timelines divide time through standardized measurements. It could therefore be useful, as a closing reflection, to ask if and how the Spotify data could have been sonified in a different way. Perhaps a less beat-driven composition would better have suited the stated purpose of the sonification?

As was repeatedly suggested in the extended review as well as by respondents in the user study, abstract types of music would allow one to avoid conventional manners of perceptualizing or presenting temporality. Certainly, such music would mean a modeling of time that is less “homogeneous” and “continuous”. At the same time, this approach would likely put higher demands on potential listeners, since it makes use of cultural forms that are appreciated by a rather limited group of people. In any case, the modeling of temporalities through sound and sonification – especially with regards to musical time – is an area that would merit further discussions and that could be the focus of future research.

A final and crucial point that needs to be highlighted in relation to the sonification design regards the limitations inherent in the Spotify data set itself, limitations that from the outset restrict what can be done through the sonification, regardless of the design choices made. As we have seen, a crucial aspect of Drucker’s critique of standard visualization conventions focuses on their tendency to obfuscate the complete lifecycle of data, presenting data not as thoroughly constructed but as unmediated representations of preexisting entities. The concept of *capta* is meant to counteract this by underlining that no data can preexist their parameterization. Using an already existing data set instead of constructing one from scratch clearly makes the demonstration of data lifecycles considerably more difficult. Moreover, in the case of the Spotify data, we are dealing with data extracted for purely commercial reasons using proprietary algorithms and machine learning systems. This makes it practically impossible to follow the inner workings of data construction (e.g., how exactly is *Valence* calculated?). It also means the data is thoroughly shaped by the instrumental motivations behind its creation: to make possible automated systems of music recommendation, which in turn are designed to make listeners stay on the platform. The processes of data capture needed for this to work decontextualize the attributes and remove the specificities of individual pieces of music, turning them instead into a set of flat numeric values. Furthermore, the categorization and manner of quantification of “audio features” reveal a set of underlying assumptions about which features of music are worth taking notice of. For instance, the reliance on (western) major/minor tonality does not only exclude many non-western types of music, but also modal music, music that makes use of alternative scales and/or systems of tuning, or that sheds harmonies all together. Furthermore, it also assumes the stability over time of audio features, even though, for instance, the perception of what makes music danceable has changed dramatically over the last 100 years.

The prototype design at least made use of a few tactics for counteracting some of these problematic aspects of the data set. For example, the design makes separated parameters such as *Danceability* and *Energy* closely interrelated and difficult to tell apart. The move away from exact readings, instead allowing the listener to “sense” the data, can also be seen as such a tactic. However, the thesis does not provide a coherent answer about how to use sonification for making the lifecycle of data transparent. What it does provide are hopefully some hints regarding possible manners for highlighting rather than obfuscating the constructed nature of data. Among the sonification examples provided in the extended literature review, we saw a rather clever attempt – through the piece *Terra Nullus* by Julian Rohrhuber (de Campo, 2009) – to demonstrate that data sets are full of holes, inconsistencies, and arbitrary choices of inclusion and exclusion. According to Drucker, standard conventions tend to hide "variations and complexities within extant data sets" and to "reduce numeric anomalies and specificities to generalizations and aggregates". This can be counteracted through innovative approaches that "reveal the multiple dimensions of data, its irregularities, complexities, variations" (Drucker, 2020, p. 131). Returning to a point made above, if the sonification prototype would have been focused on marginalized rather than mainstream music – looking for outliers rather than averages – would that not function as an innovative approach as described by Drucker? For example, rather than sonifying the most common key for each year, focus could have been directed at music that lacks key altogether. In any case, the question of how to bring attention to the lifecycle of data through sonifying it provides an interesting challenge for future humanities-minded sonification projects.

In summary, we have seen that the prototype sonification has a range of inherent limitations. However, when related to the initial aims of the thesis, these limitations – in part already pregiven through the choice of data set – do not equal failure. For one thing, they shed light on the ambitious nature of Drucker's critique and design suggestions, highlighting the demands it puts on interpretative data perceptualization. As we have seen, one important gap that Drucker has identified in much digital humanities research is its failure to develop new tools, instead being too reliant on existing and conventional ones. One reason for this failure is perhaps that that the invention of digital tools and methods that do the challenges of humanities research justice is – simply put – both time consuming and quite difficult. Apart from the difficulty of creating tools capable of facilitating multi-faceted interpretation, a tradition of digital tool creation is often absent and humanities scholars often lack sufficient coding skills. As has already been made clear above, the aim with the sonification design was never to meet all these challenges, not to mention to create a fully fledged, ready-to-use tool. This was not possible given the scope of the thesis. Instead, as was stated under purpose and aims, the sonification was meant as an early prototype: an exploratory, trial-and-error design that was to be created during a short time span. As such, it is to be understood as an early part of a process. Drucker suggests that every data visualization functions as an argument, a proposal that should be just as true when applied to data perceptualization in general. At the same time, it is an argument that allows for other types of insights when compared to a purely language-based and theoretical argument. Here lies the usefulness of the sonification design: that it uses the "language" – the potential semantics – of sound. Further, it is precisely because of its limitations and shortcomings that certain insights are brought to the fore. For instance, through the responses received in the user study, the problem with using a style of music specific for a limited period in time for representing 100 years of musical history became apparent. The same is also true for the focus on mainstream music.

Here it can also be useful to evaluate how well the implementation of Drucker's critical hermeneutics to sonification worked. One of the key initial ideas of the thesis was that at least some aspects of Drucker's theory are applicable to many forms of data perceptualization, even though it is explicitly focused on data visualization. Of course, this manner of “translating” and re-purposing theory was made necessary by the lack of existing stringent theoretical approaches to sonification from within the digital humanities – the ones found under Previous research were rather fragmented and not particularly comprehensive. Therefore, one of the core goals of the thesis was to contribute to the building of a more extensive theoretical framework, using Drucker as a point of departure. However, the challenges of modeling temporality discussed above show that there is no straightforward way of translating insights drawn from visualization into sonification, even when dealing with similar types of problems (i.e., how does one practically go about perceptualizing time as relational and social). On the other hand, when moving beyond the practical concerns of actual design, the investigation has found a clear affinity between Drucker and a number of theoretical and methodological perspectives found within the field of sonification. For instance, Drucker’s insistence that every act of reading has to be thought of as a negotiation between the “text” and the reader, and that the reader cannot be understood in isolation from socio-historical contexts, found an apparent counterpart in the theories of the listener highlighted in the extended literature review. For future research that would like to build on the findings of this thesis, the challenge would be to convert these theoretical insights into actual designs. For example, what types of sonification design could be possible following Schaeffer's phenomenology of listening? Or, how can one use musical time for conveying temporality in non-conventional manners? In this thesis, through the sonification of the Spotify data set, one possible solution to a few of these challenges has been presented. As we have seen, in her book, Drucker presents a broad array of design sketches for humanistic and interpretative visualizations, ranging from descriptions of actual existing projects to yet-to-be-realized designs of a speculative nature. Perhaps, in time, it would be possible to provide a similar list of humanistic sonifications.

The issue of how humanistic sonification *can and should look* is also related to the question of *how and where* it could be used or presented. The contexts in which sonification can be useful is a matter that is only dealt with in passing in the thesis. One possible answer is utilitarian in nature: sonification is useful in contexts where appropriate visual technologies such as screens are not available or inadequate. Given the increased use of small mobile screens in many contexts, and that such screens are inadequate for more complex types of visualization, sonification might be able to find a niche here. Further, sonification can also be useful for people with visual impairments that cannot access visual materials. While this utilitarian perspective points to areas where sonification without a doubt can be useful, it also tends to assume an equivalence between visualization and sonification, seeing them only as two different means towards an identical end. However, it has been the contention throughout this thesis that the medium used for perceptualizing data cannot be seen as a neutral vessel, and that the visual and sonic modalities come with different affordances. From this follows that sound should be valued for its own sake, since it allows for unique perspectives and interpretative possibilities. Nevertheless, even if one agrees with this, it can seem hard to envision a “place” for sound and sonification. Drucker argues that there exist, in western culture, a set of prejudices regarding the image as a form of knowledge. These prejudices are probably even more entrenched in relation to (abstract and non-speech) sound. As we have seen in the extended literature review, this is a recurring argument in the sonification literature, according to which there is a culturally conditioned visual bias. This bias is partly explained by the long history of data presentation through graphical forms of expression (see for instance G. Kramer et al., 1997). Sonification is a much more recent invention and perhaps more time is needed for it to reach a wider audience. However, the question remains what the contexts are where sonification can reach beyond the rather limited group of people with a pre-existing interest in sound and sonic art that today are the ones that mainly seem to take an interest in this particular form of data perceptualization.

Judging from the literature, common arenas for presenting sonifications are the concert venue and the gallery. This once again points to the close affinity of sonification with the sonic arts. But also, it highlights a possible area of use for sonification within the digital humanities, beyond a purely scholarly context. In the thesis, focus has more or less exclusively been directed at sonification as a method for research, mainly interrogating its potential benefits for achieving goals of a research-oriented nature. However, another common usage of sonification relates to science communication and to the dissemination of research to a wider public. For the wide tent of the digital humanities, the use of computational tools and methods for purely scholarly pursuits is only one out of many areas of interest. Another major area of importance deals with the development of such tools for the cultural heritage and GLAM sectors (galleries, libraries, archives, and museums). Commonly, digital humanities research deals with the design and evaluation of digital devices and methods – e.g., visualization techniques or immersive technologies such as virtual or augmented reality – for presenting research results, collections, and other resources dealt with within this sector. In the chapter on Previous Research, we saw one or two examples of sonification designs aimed at presenting a material for non-scholars within public space, perhaps especially in the form of the *DataScapes* project (Bonnett et al., 2021). In the extended review, there were presented further examples that could be of interest for institutions within GLAM and cultural heritage, perhaps especially the various sonifications on astronomical and climate data. These few examples notwithstanding, the use of sonification for making humanities data accessible for a wider public remains largely unexplored, and would merit the attention of potential future research.

Such research would also need to consider how sonifications can be designed using many different types of humanities data. In the thesis, only one specific type of data was explored in a practical manner – the Spotify data set. This data was more than anything else used as the basis an example. The purpose of the thesis was not to shed new insight onto the past 100 years of musical development – even though that might perhaps have been an interesting side effect – but rather to explore one possible path out of many for sonifying humanities data. As one of the respondents in the user study put it: it makes sense to use sound and sonification, and especially a musical sonification, for interpreting data representing a piece of musical history. This type of "musicological" sonification could be explored much further. One would not necessarily have to use quantitative data that has been extracted from a musical archive using machine learning – as was the case in this thesis – but could for instance make use of the sound files themselves, just to ponder one possibility.

However, sonification within digital humanities would clearly not have to be limited to music-based data, but could potentially be applied to almost any form of data used within the field. One would not even have to limit the scope to quantitative data, but could experiment with turning various types of qualitative data into sound. This could for instance be achieved through working with memory institutions within GLAM, as described above. These institutions could make available data curated specifically for the needs of humanities research. Instead of being dependent on data extracted through commercial platforms or on purely quantitative data, collaboration with memory institutions could potentially yield data structured in ways that keep intact much of the complexity of humanistic subject matters. For instance, such data could retain rather than flatten and eliminate the micro level – as was the case with the Spotify data – not only making possible quantitative, macro-level analyses, but also allowing one to "zoom" to individual instances, providing in-depth contexts (as with the CIDOC Conceptual Reference Model, see Oldman et al., 2016). Sorting out which forms of data would be suitable for the method of sonification – as well as figuring out exactly how the data can be sonified – provides one task for future research.

As we have seen throughout the thesis, the use of sonification within the context of (digital) humanities is largely uncharted territory. It is probably fair to say that there exist an almost endless array of imaginable possibilities through which humanities data can be expressed, explored, and interpreted through sound, not only in relation to the development of individual sonification designs, but also regarding the kind of data used and the context within which it is presented. And while this thesis has focused on sonification as a stand-alone form of data perceptualization, one can imagine a range of ways in which sound can be combined with other modalities and digital methods. Various forms of audio-visual data perceptualization – common within the sonification community at large – are easy to imagine, and could for instance add sound to visualization suggestions provided by Drucker. One could also conceive of projects similar to DataScapes and Soundmarks – as presented in the chapter on previous research – where sonification is used in conjunction with movement through space, or of tactile objects that generate sonified sound in various ways. The possibilities are vast, and it is an area that would merit future research.

Again, as a whole, the field of sonification remains somewhat scattered and is comprised of a rich variety of theoretical and methodological perspectives. From a digital humanities perspective, this should be perceived as beneficial since it signals a lack of well-established conventions. For Drucker, one of the main problems with data visualization is the existence of such conventions. They make it all too convenient to simply start using one of the existing and often user-friendly tools, even though it is not well suited for the humanities. With sonification, a lack of conventions and of standardized tools means that sonic data perceptualization becomes far less convenient and more time-consuming, and that the threshold for getting things done becomes higher. But, as Drucker has convincingly shown, when the convenience in fact hampers the achievement of the goals of humanities research, it is illusory. Without conventions, one is instead forced to engage in experimentation and invention, activities that have always been at the core of the ever-changing field of the digital humanities. Paradoxically, it is perhaps through the more cumbersome process of experimenting and inventing that data research can be made consistent with the traditions and aims of the humanities.

10 Conclusion

Sonification is a method of data perceptualization that uses sound as a means for exploring, communicating, and interpreting relations and occurrences within sets of data. The overarching aim of the present thesis has been to explore the potential implementation of sonification within the digital humanities. Using the critical hermeneutics of Johanna Drucker as its theoretical framework, the thesis has paid close attention to how data perceptualization in the humanities needs to tackle radically different challenges when compared with the natural and empirical sciences. Humanities research often involve dealing with heterogeneity, ambiguities, and a multitude of possible interpretations inherent in its objects of study. The research problem addressed deals with the capacity of sonification to reflect and successfully deal with these challenges. As methods of investigation, a combination of theoretical and practical approaches were used. First, a review of literature drawn from the existing field of sonification was conducted. The aim of this review was to locate and highlight existing theoretical and methodological perspectives with affinities to Drucker's critical theory. Second, a sonification prototype was designed using the SuperCollider audio programming language. It was based on data drawn from Spotify covering music released over a hundred years. The purpose of the sonification was to put into practice some of the findings of the extended review, as well as to demonstrate in a practical manner methods for dealing with the challenges of sonifying humanities data. As closing part of the thesis, the sonification was evaluated through a small user study.

One important finding of the thesis was that the method of sonification remains largely unexplored in the digital humanities. Further, within the wider field of sonification, there are very few examples of projects or theoretical perspectives dealing explicitly with humanities research, and data is primarily drawn from the natural sciences. At the same time, there exist within the field a wealth of theories and methodologies with clear affinities to critical and humanistic perspectives. This means that there is no need for potential digital humanities' sonification projects to re-invent the wheel. Instead, they can draw on lessons already learned elsewhere. For instance, through the insights of embodied cognition, sound can be understood permeated with meaning, and not simply as a transmitter of information. However, the design of humanities sonifications will also need to involve a great deal of invention and experimentation. This was apparent through the sonification prototype created for the thesis. While the design could draw on theoretical insights gained in the extended literature review, not least on the concept of musical sonification, it also lacked clear precedents of a practical nature. This meant that the sonification had to be invented more or less "from the ground up".

In conclusion, the thesis contends that sonification can and should be included among available methods for perceptualizing data within the digital humanities. One overarching argument for this is that sonification should not be seen as equivalent to other forms of data perceptualization such as visualization. Instead, the modality of sound comes with its own affordances, strengths and drawbacks, meaning it can be used for presenting unique perspectives on sets of data. In the context of the digital humanities, sonification offers a number of strategies for interpretative data perceptualization, avoiding the pitfalls of a positivist and representational paradigm. For example, through the strategy of *musical sonification*, rather than presenting the sonification as a "true" representation of underlying data, perceptualization as an act of interpretation can be made visible. The strategy was implemented in the sonification prototype, which was designed so that data could be "sensed" or experienced rather than simply transmitted or communicated. The user study confirmed that this aim was at least partly successfully realized, and hopefully the prototype can provide inspiration for future digital humanities sonification projects.

As for potential future research, this thesis has only been able to begin scratching the surface. The fact that very little has been written about sonification from an explicit digital humanities perspective means that there exist many paths to be explored. First and foremost, future research has to further develop methodologies and study how the rather abstract theoretical standpoints explored in this thesis can be practically realized through the design of actual sonifications. This would need to involve the invention of new tools and experimenting with designs, activities that could be said to be part of the core of the practice of digital humanities. It would also need to clarify in greater detail the affordances of sonification in relation to humanities research. Future research should also explore the various contexts in which sonification could be used. In this thesis, focus has been directed at sonification as a stand-alone form of perceptualization in the context of research, making use of only one set and type of humanities data. However, one could easily imagine many other areas of use. For instance, sonification could be implemented as a method for communicating data, research, or collections within the heritage and GLAM sectors. Such research would need to explore and experiment with the sonification of many types of humanities data. In this context, sonification could also form part of multimodal and/or interactive systems, where the use of sound can be combined with visual, textual, or immersive elements. Drawing on the findings and conclusions of this thesis, it can be argued that sonification holds great potential within all these areas of use.

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Appendix 1: Databases included in search

ACM digital library, ACS (American chemical society), AIP (American institure of physics), Altmetric Explorer, AM Explorer, Annual reviews, APS (American physical society inkl. PROLA), ArtikelSök, ASM (American society for microbiology), ATLA religion database, BDSL (Bibliographie der Deutschen Sprach- und litteraturwissenschaft), BMJ (British medical journals), Brill journals, Brill online reference works, Britannica Academic, BSU (Business source ultimate), Cambridge Core, Cambridge EBA HSS, Cell press, Cinahl with fulltext, Cochrane library, Communication abstracts, Criminal justice abstracts, De Gruyter, Dewey online (Past masters), Ebook academic complete, Ebook central, Ebsco ebook collection, Elsevier SD reference works, Emerald ebooks, Emerald journals premier, EmiWeb, Film & television literature index with fulltext, Forest science, Författningshandbok online, Gale ebooks (Gale virtual reference library), Gale research complete, Hit songs deconstructed, Holdings, Human kinetics, IEEE Xplore, JSTOR, KBT-podden, KLG (Kritisches lexikon zur deutschsprachigen gegenwartsliteratur), Lecture notes in computer science, Leisure tourism, MathSciNet, MLA (Modern language association), Nature journals, Naxos music library, NBER, OED (Oxford English dictionary), Oxford art online, Oxford Dictionary of National Biography online, Oxford journals, Oxford music online, Oxford reference, PLOS, Predatory reports, Project MUSE, Psycinfo, PsycTherapy, Regs4ships, RILM (abstracts of music literature) with fulltext, SAGE journals, SAGE Reference, ScienceDirect freedom collection, SciFinder, SciFree journal search tool, SciVal, Scopus, SIS abonnemang, Social science premium collection (ASSIA, ERIC, IBSS, LLBA, LISA, PAIS, Sociological abstracts (inkl. Social services abstracts), WPSA m fl, SPORTDiscus, Springer compact, Springer Nature ebooks, Springer Nature fully OA, SRM (Sage Research methods) core, SRM (Sage Research methods): cases I, Statista, Taylor & Francis, Visible body, Web of science (inkl. ESI, JCR), Wiley journals, Wiley online library

Appendix 2: User study questionnaire

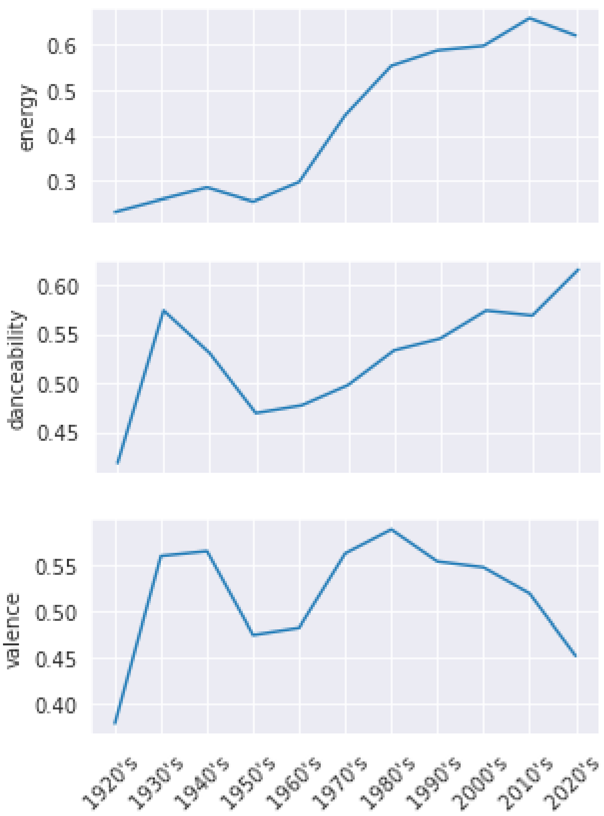
Document made available to respondents explaining sonification design

Survey regarding Spotify data set sonification

Data sonification involves the translation or remediation of sets of data into sound in order to make structures within the data perceptible for humans. It can be seen as an alternative to data visualization. The purpose of the present survey is to gather user feedback to an experimental sonification design which is based on a data set gathered from Spotify. The sonification can be found here: https://soundcloud.com/klangfigurer/spotify-dataset-sonification

The data set

The set used for the sonification contains data extracted from Spotify. The data is drawn from a total of 169,910 sound files or tracks recorded during the years 1921-2020. While mostly music of all types and genres, a number of sound files also contains recordings of speech (radio shows, podcasts, poetry readings, etc.). For each track, a Spotify ID, artist name and name of piece is given, as well as release year and track duration. Further, a number of "audio features" are defined in the data set. In some cases, these audio features represent straight forward musical features of tracks such as tempo in Beats Per Minute (BPM), key or mode (minor/major). In other, they describe more abstract musical features such as the "danceability" or "energy" of a track. This latter type of feature is represented through a numerical (floating point) value ranging from 0 to 1.



In the sonification, the following six audio features have been used. As an aid to the listener, graphs outlining the development over time of the more abstract audio features is provided.

Danceability: Describes how suitable the track is for dancing, based on a combination of musical elements such as tempo, rhythm stability, beat strength and overall regularity.

Energy: Represents "a perceptual measure of intensity and activity". Tracks with high value feels "fast, loud and noisy". The measure is based on attributes such as loudness, timbre and dynamic range.

Key: Extracts the main key of the track as represented by an integer value ranging from 0-11, where 0=C, 1=C#/Db, etc.

Mode: Analyses whether the track is mainly in the major or minor mode, based on the type of scale that the main melodic material is based on. Has only two possible values, major or minor.

Tempo: The overall tempo of the track in Beats Per Minute (BPM).

Valence: Describes the "musical positiveness conveyed by the track". Tracks with high value "sound more positive (e.g. happy, cheerful, euphoric)", while a low value signals music that is "sad, depressed, angry".

Sonification design

The overall aim of the sonification is to make long-term trends in the data perceptible, thereby perhaps being able to say something about the development of popular music during the last 100 years. Genre-wise, the sonification can be described as a stripped-down, elementary electronic music or techno piece. At its center is found a rather simple rhythmic structure: a steady beat as underlined by a layer of percussive sounds. Each year of data is represented by four beats of music, each beat being highlighted by a hit with the kick drum and every second beat is accentuated by a snare drum. Given that the overall tempo of the piece fluctuates between around 100-120 Beats Per Minute (BPM), each year is represented by 2-2.4 seconds of music. This means that the whole piece has a duration of around 3 ½ minutes. Sound-wise, the piece is comprised of three distinct sonic layers: a bassline, percussion and a repeated chord. The percussive layer consists of a kick drum, open and closed hihats, and a snare drum.

With the exception of **Key**, the data was prepared by calculating the average value for each year. It is this average value that is the basis of the generation of sound, and that is thus "played" by the sonification. With **Key**, only twelve values are possible. Therefore, rather than an average, the most common key for each year was calculated. Another special case is the **Mode** value. Since a quick overview made clear that the major mode is the most popular mode for every single year that is represented in the data, an approach was chosen that calculates how common the two modes where in to relation to each other for each year. This resulted in a value between 0 and 1, where for instance 0.75 means that the major mode was used in 75% of the songs and minor in the rest, while 0.25 would mean that it was used in 25% of cases, and so on.

A few parameters are mapped in a direct and fairly obvious manner. The representation of each year in the data by four beats/bars of music means that the time flows forward in a linear manner. Further, the **Tempo** value is mapped directly onto the tempo of the piece, meaning that the sonification is played in accordance with the average BPM for each year. However, in order to avoid abrupt changes in tempo between years, the BPM changes very gradually, transitioning between values in a smooth manner. This means that changes in tempo in the data only becomes visible (or “hearable”, rather) in the form of long-time trends. Finally, as for **Key** for each year, the value is mapped directly onto the bassline, which plays the root note of the most popular key for each year. In a similar manner, the most popular key is also played by the chord layer, in the form of simple triad chord. Here however, in order to avoid constant and abrupt chord changes between individual years, a chord change only takes place if a specific key is the most popular one for at least three years in a row.

In contrast, a much more complex process of correlating sound to data is implemented in relation to the musical attributes of **Energy**, **Danceability**, **Valence**, and **Mode**. Instead of letting these qualities be represented by single and easily recognizable sound attributes, they are expressed through a combination of sonic patterns and events. In the case of **Energy**, elements of randomness are also included:

For **Danceability**, a simple form of direct mapping on the percussive layer is combined with more subtle forms of manipulation of the bass line. The volume of the percussive layer is dependent on the value for Danceability: the higher the value, the louder the percussion. At the same time, the characteristics of the bass line is correlated with danceability, the bass line becoming more pronounced with higher values. This is achieved by lowering the attack and release time for the bass notes, both for volume and for the low-pass filter that is used on top of the bass synth. This means that when Danceability is low, the bass notes tend to overlap each other, making them more softened and muted, and therefore overall less distinguishable. Vice versa, when Danceability is high, the bass notes are more distinct, giving more "drive" to the bass line, giving it more of a percussive quality.

For **Energy**, the general idea is that the higher the value, the more energetic the music becomes. This is achieved through manipulation of the percussion and chord layers. For the percussion, there is a certain chance of extra hits with the kick drum, snare drum and hihats. With a higher value of Energy, this chance increases, generally causing a thicker and more intense percussive layer. For the chord layer, higher Energy results in a sound that is more harmonically rich, while lower values make the sound softer and more muffled. This effect is accomplished using a simple low-pass cutoff filter which allows for higher frequencies with higher Energy. The resonance value of the filter is also correlated to Energy, with sharper resonances being caused by higher values.

For **Valence**, its value affects the characteristics of the sound of the chord layer. This audio attribute is perhaps the most ambiguous of the ones used in the sonification, given that it is meant to reflect the emotional content or character of the music. In the sonification, lower valence values, ostensibly representing music that is “sad, depressed, angry”, is interpreted as *dissonance*. Vice versa, higher values, reflecting musical content that is “happy, cheerful, euphoric” (Spotify, n.d.), are expressed through the use of (musical, harmonic) *consonance*. In practice, the valence value is translated into a detuning of the synth chord: with high values, the main chord is more harmonious, while a lower value adds dissonance to it.

Finally, **Mode** is mapped directly onto the main chord layer. In this layer, the synth plays two chords: first, a major chord in the most popular key of the present year. Two beats later, this chord is followed by the parallel minor (e.g., C major followed by A minor). The Mode value decides the relative volume for each of these chords. For instance, for a year where major is the main mode for 75% of the songs, the volume of the minor chord is one third of that of the major chord. Both the chords have a rather long duration (in total 2.3 seconds). This design decision is based on the assumption that a listener will encounter the chords not simply as two separate musical events, but as overlapping each other, fusing them. The idea is that the listener will experience the chord layer as a continuous harmonic flow rather than distinct chords, in which the relative volume of the two chords will be experienced as degrees of "major-ness" and "minor-ness".

Links and further information

The descriptions of the Spotify audio features have been drawn from:
https://developer.spotify.com/documentation/web-api/reference/#/operations/get-audio-features)

The graph has been borrowed from (which contains further information on the data set):
https://jovian.ai/parasbisht126/spotify-data-analysis-kaggle-1

Google forms document - questionnaire

Spotify sonification survey

This survey is part of a master's thesis in Digital Humanities at Linnaeus University, Sweden. The thesis explores the use of sonification as a method for engaging with data within the humanities. As part of the thesis work, a sonification prototype has been created. The sonification is based on data extracted from Spotify covering music recorded during the years 1921-2020. Through the sonification, the following question is asked: is it possible to follow and interpret trends in music during 100 years through the rendering of such data into sound?

Below, there are two links. One contains a document describing the sonification design and the data used, the other leads to the sonification sound file.
https://drive.google.com/file/d/1qcswhdi8nMQNCnHLTsb1CP9zJ8GsdEcZ/view?usp=sharing
https://soundcloud.com/klangfigurer/spotify-dataset-sonification

Please read the document, listen to the sonification and answer the questions provided below.

Thank you for your participation!
1. Briefly describe your occupational/academic background and areas of expertise

2. Have you come across the concept of data sonification before? If yes, in what context?

3. Does the overall idea of sonifying data gathered from Spotify make sense to you? What practical applications do you see possible?

4. When listening to the sonification, are you able to identify how Spotify audio features have been translated into sound?

5. Are some audio features easier to identify and follow than others? If so, which ones and why?

6. Are you able to follow the unfolding of long term trends in the data through sonification? Are some trends easier to follow than others, and if so, why?

7. Did the overall sonification design and the connection between the audio features and sound seem reasonable to you?

8. Would you suggest different mappings between the data and the audio features?

9. What is your overall impression of the sonification as a piece of music? Do you think it can be described as music? Do you find it appealing? Why/why not?

Appendix 3: SuperCollider code

```
// 1. DATA PREPARATION

// The data preparation methods presented in this section of code drew a lot
of inspiration from: https://github.com/maszkowicz/SuperCollider/blob/master/
3_simple_sonification.scd

// Row 0: 0 id; 1 name; 2 artists; 3 duration_ms; 4 release_date; 5 year; 6
acousticness; 7; danceability;  8 energy; 9 instrumentalness; 10 liveness; 11
loudness; 12 speechiness; 13 tempo; 14 valence; 15 mode; 16 key; 17
popularity; 18 exlicit

// In reduced file: 0 duration_ms; 1 year; 2 acousticness; 3; danceability;
4 energy; 5 instrumentalness; 6 liveness; 7 loudness; 8 speechiness; 9 tempo;
10 valence; 11 mode; 12 key; 13 popularity; 14 explicit


File.exists("c:/SuperColliderFiles/reducedSpotifyData.csv"); // Check that
the file exists

~spotifyData =
CSVFileReader.read("c:/SuperColliderFiles/reducedSpotifyData.csv",
skipEmptyLines: true, skipBlanks: true);

~spotifyData.removeAt(0); // Remove first row containing descriptive strings


( // Iteration that makes sure each column is the right data type (integer or
float)
~spotifyData.do( { arg row, i;
		~spotifyData[i].asArray[0] =
~spotifyData[i].asArray[0].asInteger; // duration_ms
		~spotifyData[i].asArray[1] =
~spotifyData[i].asArray[1].asInteger; // year
		~spotifyData[i].asArray[2] = ~spotifyData[i].asArray[2].asFloat;
// acousticness
		~spotifyData[i].asArray[3] = ~spotifyData[i].asArray[3].asFloat;
// danceability
		~spotifyData[i].asArray[4] = ~spotifyData[i].asArray[4].asFloat;
// energy
		~spotifyData[i].asArray[5] = ~spotifyData[i].asArray[5].asFloat;
// instrumentalness
		~spotifyData[i].asArray[6] = ~spotifyData[i].asArray[6].asFloat;
// liveness
		~spotifyData[i].asArray[7] = ~spotifyData[i].asArray[7].asFloat;
// loudness
```

```
        ~spotifyData[i].asArray[8] = ~spotifyData[i].asArray[8].asFloat;
// speechiness
        ~spotifyData[i].asArray[9] = ~spotifyData[i].asArray[9].asFloat;
// tempo
        ~spotifyData[i].asArray[10] =
~spotifyData[i].asArray[10].asFloat; // valence
        ~spotifyData[i].asArray[11] =
~spotifyData[i].asArray[11].asInteger; // mode
        ~spotifyData[i].asArray[12] =
~spotifyData[i].asArray[12].asInteger; // key
        ~spotifyData[i].asArray[13] =
~spotifyData[i].asArray[13].asInteger; // popularity
        ~spotifyData[i].asArray[14] =
~spotifyData[i].asArray[14].asInteger; // explicit
} );
)


// A function that removes tracks with speechiness above 0.66, given that
thses are probably radio shows or other speech-based recordings, not music
(
for ( ~spotifyData.size-1, 0, {
        arg i;
        if ( ~spotifyData.at(i).asArray.at(8) > 0.66,
{ ~spotifyData.removeAt(i) } );
});
)

// Creates a number of arrays for the various parameters, each containing 100
slots for 100 years
(
~acousticness = Array.newClear; ~acousticness = Array.series(100, 0, 0);
~danceability = Array.newClear; ~danceability = Array.series(100, 0, 0);
~energy = Array.newClear; ~energy = Array.series(100, 0, 0);
~tempo = Array.newClear; ~tempo = Array.series(100, 0, 0);
~valence = Array.newClear; ~valence = Array.series(100, 0, 0);
~mode = Array.newClear; ~mode = Array.series(100, 0, 0);
~instrumentalness = Array.newClear; ~instrumentalness = Array.series(100, 0,
0);
~key = Array.newClear; ~key = Array.series(100, 0, 0);
)


// Calculates the avarage value for each year for each parameter
(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);
```

```
~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~acousticness[year] = ~acousticness[year] + track.asArray.at(2);
		~counter[year] = ~counter[year] + 1;
} );

~acousticness.do( { arg value, i;
		~acousticness[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~danceability[year] = ~danceability[year] + track.asArray.at(3);
		~counter[year] = ~counter[year] + 1;
} );

~danceability.do( { arg value, i;
		~danceability[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~energy[year] = ~energy[year] + track.asArray.at(4);
		~counter[year] = ~counter[year] + 1;
} );

~energy.do( { arg value, i;
		~energy[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~tempo[year] = ~tempo[year] + track.asArray.at(9);
		~counter[year] = ~counter[year] + 1;
} );
```

```
~tempo.do( { arg value, i;
		~tempo[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~valence[year] = ~valence[year] + track.asArray.at(10);
		~counter[year] = ~counter[year] + 1;
} );

~valence.do( { arg value, i;
		~valence[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~inatrumentalness[year] = ~instrumentalness[year] +
track.asArray.at(5);
		~counter[year] = ~counter[year] + 1;
} );

~instrumentalness.do( { arg value, i;
		~instrumentalness[i] = value / ~counter[i];
} );
)

(
~counter = Array.newClear; ~counter = Array.series(100, 0, 0);

~spotifyData.do( { arg track;
		var year = track.asArray.at(1) - 1921;
		~mode[year] = ~mode[year] + track.asArray.at(11);
		~counter[year] = ~counter[year] + 1;
} );

~mode.do( { arg value, i;
		~mode[i] = value / ~counter[i];
```

```
//		~mode[i] = (~mode[i] + 0.5).asInteger; // Major/Minor rounds to
one of two possible states
} );
)


// key: an array with 12 slots, each year, check which key is most common,
add to ~key array
(
~counter = Array.newClear; ~counter = Array.fill2D(100, 12, 0);

~spotifyData.do( { arg track;
		var year = track.asArray[1] - 1921;
		var key = track.asArray[12];
		~counter[year].asArray[key] = ~counter[year].asArray[key] + 1;
} );

100.do( { arg year;

		~commonKey = 0;
		~largestValue = 0;

		~counter[year].do( { arg key, i;
				if ( key > ~largestValue, { ~largestValue = key;
~commonKey = i } );
		} );

		~key[year] = ~commonKey;
} );
)

//
==============================================================================
=======

// 2. RESULTING AND FINAL ARRAYS

// Depending on the computer used, the calculations in the dataPreparation
can take time, and can take quite a heavy toll on memory resources. Therefor,
the resulting arrays are collected here for quick access.

(

~acousticness = [ 0.8958234375, 0.93923611111111, 0.97624161309524,
0.9355745443038, 0.96530534351145, 0.94649896899225, 0.93439082510135,
0.96199766124662, 0.96624698795181, 0.94392107154696, 0.94083795066414,
0.93788814317673, 0.90466303430421, 0.89210762335766, 0.91960149905124,
```

```
0.89470158266819, 0.89940572390572, 0.91512991016043, 0.8883489154334,
0.93197465581977, 0.89922700312175, 0.85004191264508, 0.91527600644123,
0.94193472783357, 0.91525633802817, 0.93148612881356, 0.91703954,
0.93377571660357, 0.90964567958656, 0.87553756419491, 0.90875355072239,
0.90119155208913, 0.897440881823, 0.86888955293495, 0.8486768009739,
0.81962137896326, 0.78986167334669, 0.77804027541312, 0.77670118721461,
0.75622584436584, 0.7503708774584, 0.7128227027163, 0.71155599094567,
0.68418114516945, 0.60505629076224, 0.53248132242089, 0.51619004279699,
0.48766855613065, 0.44276864229804, 0.45280174482241, 0.45057687244847,
0.45639179769424, 0.41186632448673, 0.43710546432866, 0.41335647732026,
0.36216209189785, 0.33157557050576, 0.31535652241604, 0.27865727762959,
0.28263393225613, 0.29213742518259, 0.27704104955511, 0.2718740224773,
0.27105263466967, 0.27737492249749, 0.2670351368583, 0.30071363181181,
0.301803968999, 0.29973838873811, 0.30330735043108, 0.31584468818819,
0.30607506391087, 0.28992108497492, 0.28829847714357, 0.28457893747495,
0.28589013857715, 0.29945251356495, 0.27709241216149, 0.26115954503271,
0.2862695415982, 0.26969971680521, 0.27499810355355, 0.24632508220942,
0.26236926791165, 0.24624229831579, 0.26550223237857, 0.24107647601402,
0.24047559565566, 0.24083712435264, 0.22401941899799, 0.23827731185371,
0.23525847416625, 0.2419500096994, 0.23730597851277, 0.24654017598131,
0.27947577740835, 0.28963073696545, 0.2717614254509, 0.29003699899447,
0.24726105637921 ];

~danceability = [ 0.4256609375, 0.48, 0.56718452380952, 0.54865400843882,
0.57230152671756, 0.51007751937985, 0.64948648648649, 0.51794399277326,
0.60798132530121, 0.51017093922652, 0.52768918406072, 0.5581485458613,
0.60336197411003, 0.52877372262774, 0.48793017077799, 0.50423591790194,
0.55667390572391, 0.48341087344029, 0.50473974630021, 0.47865,
0.47943714880333, 0.46432449602932, 0.46390515297907, 0.48953543758967,
0.45071992957746, 0.39876698305085, 0.46816541935484, 0.43763109789075,
0.43495870801034, 0.48007722457627, 0.45299339525284, 0.43809364902507,
0.43007154213037, 0.45559328397673, 0.48252778067885, 0.48434519375944,
0.5070870240481, 0.48131487230846, 0.48747189244038, 0.48671430015159,
0.48892496217852, 0.49884869215292, 0.4857514084507, 0.50558093070309,
0.50450994447249, 0.50333360120542, 0.49813859649123, 0.50030989949749,
0.49037516307075, 0.50930465232616, 0.50389477124183, 0.520535839599,
0.51334041061592, 0.52016427855711, 0.52394670688788, 0.53250731096645,
0.53714842263395, 0.54488546365915, 0.56148897835933, 0.55786843421711,
0.54185067533767, 0.56569802831143, 0.54809974772957, 0.53963683683684,
0.55894217652959, 0.54435834594049, 0.54289364364364, 0.54498123123123,
0.55203790686029, 0.54500786967419, 0.56119694694695, 0.56377651477216,
0.57438375125376, 0.55945242621311, 0.56482059118236, 0.59169383767535,
0.57797426988923, 0.59285095285858, 0.58588132863613, 0.5891872745491,
0.58592403605408, 0.57857942942943, 0.57678181362725, 0.57218162650602,
0.57596501253133, 0.56852003004507, 0.56487285928893, 0.58353653653654,
0.56716408060453, 0.57783348439074, 0.55984033066132, 0.57178828242364,
```

```
0.57880385771543, 0.58955998998498, 0.59078276220145, 0.5999483197556,
0.61227330996495, 0.66508617234469, 0.64345434891905, 0.67264820102798 ];

~energy = [ 0.23678359375, 0.23702625, 0.24637619047619, 0.3470329113924,
0.26364885496183, 0.22454786046512, 0.25647060810811, 0.20464577235772,
0.23468554216867, 0.3269958839779, 0.25924232068311, 0.29004071588367,
0.28655550161812, 0.25837737226277, 0.27344276091082, 0.29750920205245,
0.28651638047138, 0.28306096256685, 0.2985588794926, 0.35907840425532,
0.26150017689906, 0.2570479352474, 0.27420181964573, 0.2567768579627,
0.2477553943662, 0.20430268474576, 0.25886823225806, 0.24893959167117,
0.24479480103359, 0.32857356461864, 0.25230465428277, 0.24930925905292,
0.26490293587705, 0.26419958751983, 0.28891560835509, 0.30653465022647,
0.29694559118237, 0.31122597396094, 0.3149002435312, 0.34615479535119,
0.34061147150782, 0.38022566901408, 0.37147206740443, 0.39732823975721,
0.44428334477537, 0.47250457559016, 0.45266250125313, 0.45684245728643,
0.48969621675866, 0.4969156078039, 0.50145686777275, 0.50741794486216,
0.53504380570856, 0.52227847194389, 0.533602760181, 0.55662743615423,
0.56428713970956, 0.57008016541354, 0.59937027176648, 0.60082852426213,
0.60154328914457, 0.5999999388271, 0.6158910443996, 0.60143295295295,
0.61075729187563, 0.62003540090772, 0.58809103603604, 0.59382523523523,
0.59184145718578, 0.58740822055138, 0.56596468468469, 0.58966479218828,
0.57185160982949, 0.59061164532266, 0.58969821142285, 0.59184329158316,
0.6025119286002, 0.61504851554664, 0.64239979718168, 0.62221276553106,
0.63842782774161, 0.65148427427428, 0.66567189378758, 0.66164012048193,
0.66036847619048, 0.65753633950926, 0.67310045067602, 0.67564804034034,
0.67976893198992, 0.69284829315206, 0.67164385370742, 0.66943349023535,
0.65671511908818, 0.65370908522784, 0.63399285280374, 0.59309680269857,
0.58657444857286, 0.59060688376753, 0.57961197913524, 0.61237254140491 ];

~tempo = [ 100.3977578125, 101.37613888889, 112.40403571429, 120.65335864979,
115.83766030534, 105.13808992248, 114.75013851351, 106.44821680217,
115.67479718875, 110.17605801105, 107.61166034156, 118.04981879195,
115.115197411, 116.3548959854, 111.22795540797, 111.47549486887,
114.63101851852, 111.87393226381, 114.60310676533, 107.51900750939,
107.31441727367, 106.25687965791, 106.37383091787, 107.12776901004,
107.63146830986, 102.6109938983, 109.40356967742, 107.50399242834,
109.25199741602, 112.24528866525, 109.26953663571, 107.67628523677,
109.06761685215, 108.91748439979, 110.66004856397, 111.78379315551,
112.33498847695, 112.89547070606, 112.48011872146, 113.06302273876,
112.3758809884, 114.996777666, 114.6500417505, 115.29822964087,
117.69019636547, 116.37848468106, 117.60795137845, 116.56686482412,
116.96708730557, 117.25086843422, 118.37928557064, 119.27930225564,
120.41175463195, 119.86297895792, 119.26458320764, 121.17108763145,
122.08090335503, 121.1515754386, 123.11203220936, 122.6834142071,
123.42566033017, 121.3923776542, 121.4867346115, 121.94098098098,
122.05312888666, 121.17277811397, 120.40147797798, 120.49951351351,
120.62122533801, 120.06281854637, 119.76325975976, 122.61105007511,
```

```
119.93881043129, 118.41389744872, 119.1600260521, 117.35100751503,
117.89463796576, 118.54524824473, 119.79038097635, 118.88761773547,
117.95147421132, 119.60305955956, 121.07334168337, 121.78076556225,
122.2242235589, 121.862444667, 123.46349123686, 123.48694394394,
123.85478639798, 123.5688489426, 122.47687324649, 122.15018427641,
120.68898296593, 122.53492839259, 119.71782658359, 119.09911710794,
116.88632699049, 121.98833917836, 118.81840573152, 121.22941976014 ];

~valence = [ 0.42549453125, 0.53405555555556, 0.62372678571429,
0.66857383966245, 0.6167679389313, 0.51565009302326, 0.65948108108108,
0.47884110207769, 0.63411626506024, 0.61830392265193, 0.57011214421252,
0.5955644295302, 0.63677896440129, 0.56353886861314, 0.51856223908918,
0.53575062713797, 0.59389511784512, 0.51799039215686, 0.56367959830867,
0.62317956195244, 0.47972414151925, 0.47227165546732, 0.51695523349436,
0.55359397417504, 0.46119514084507, 0.37092888135593, 0.50390090322581,
0.44361535965387, 0.42809545219638, 0.55448808262712, 0.43134122807018,
0.43815940061281, 0.4203240063593, 0.44628244315177, 0.47287195822454,
0.50615148465023, 0.51449634268537, 0.49501792689034, 0.48680314561137,
0.52792475997979, 0.51877917297025, 0.56092791750503, 0.55054406438632,
0.56684673748103, 0.57762993437658, 0.58601361125063, 0.55828586466165,
0.5673575879397, 0.55703611138986, 0.57481815907954, 0.57513232780292,
0.59725964912281, 0.58756765147722, 0.58800961923848, 0.58005600804424,
0.58485913870806, 0.58839323985979, 0.59564937343358, 0.61210991444389,
0.60349564782391, 0.583316008004, 0.59473003033367, 0.57960807265389,
0.56696817317317, 0.57206028084253, 0.5563262228946, 0.54265645645646,
0.55422062562562, 0.55865593390085, 0.53414546365915, 0.55408738738739,
0.56469414121182, 0.5588110330993, 0.53702756378189, 0.53690616232465,
0.56437950901804, 0.54752472306143, 0.54563911735206, 0.55811333668848,
0.55776958917836, 0.551117776665, 0.54778828828829, 0.53557009018036,
0.53079262048193, 0.53311082706767, 0.52132188282424, 0.51529003505258,
0.531648998999, 0.511684502267, 0.52670420946626, 0.47966331162325,
0.47488509764647, 0.467175250501, 0.46466194792188, 0.44384515057113,
0.43044206720978, 0.41427418627942, 0.44727246492986, 0.46609715434892,
0.48290521987436 ];

~mode = [ 0.65625, 0.625, 0.77380952380952, 0.75105485232068,
0.72137404580153, 0.72713178294574, 0.65540540540541, 0.70189701897019,
0.73493975903614, 0.67900552486188, 0.70018975332068, 0.73601789709172,
0.7168284789644, 0.73540145985401, 0.72675521821632, 0.73318129988597,
0.71212121212121, 0.76648841354724, 0.72832980972516, 0.64643304130163,
0.69302809573361, 0.73182651191203, 0.72302737520129, 0.69153515064562,
0.72887323943662, 0.69966101694915, 0.72516129032258, 0.67441860465116,
0.73385012919897, 0.69544491525424, 0.73942208462332, 0.74930362116992,
0.7371489136195, 0.72924378635643, 0.66057441253264, 0.69652742828384,
0.67985971943888, 0.72258387581372, 0.7376966007103, 0.74684183931278,
0.72213817448311, 0.72987927565392, 0.74496981891348, 0.76327769347496,
0.79101463907118, 0.75339025615269, 0.75689223057644, 0.77738693467337,
```

```
0.75564475664827, 0.77738869434717, 0.75666163901458, 0.74786967418546,
0.76314471707561, 0.74448897795591, 0.7420814479638, 0.72608913370055,
0.73159739609414, 0.72080200501253, 0.71967790639155, 0.74037018509255,
0.71585792896448, 0.69716885743175, 0.69475277497477, 0.7047047047047,
0.69709127382146, 0.70700958144226, 0.73323323323323, 0.70870870870871,
0.71457185778668, 0.7218045112782, 0.74024024024024, 0.75112669003505,
0.73971915747242, 0.71535767883942, 0.7314629258517, 0.70691382765531,
0.70292044310171, 0.697592778335, 0.694514343231, 0.68587174348697,
0.69654481722584, 0.69219219219219, 0.69338677354709, 0.67670682730924,
0.68872180451128, 0.67751627441162, 0.68903355032549, 0.69469469469469,
0.68816120906801, 0.70342396777442, 0.69288577154309, 0.65398097145719,
0.65781563126253, 0.67801702553831, 0.62253374870197, 0.63900203665988,
0.62493740610916, 0.61322645290581, 0.62242332830568, 0.60651056539121 ];

~key = [ 2, 4, 0, 10, 5, 5, 7, 10, 7, 2, 5, 5, 5, 0, 7, 0, 7, 0, 0, 7, 7, 7,
5, 7, 7, 7, 0, 0, 0, 7, 0, 0, 0, 5, 0, 0, 5, 0, 0, 5, 0, 0, 0, 0, 0, 9, 0, 0,
2, 2, 2, 2, 0, 7, 9, 2, 9, 9, 9, 0, 9, 2, 9, 9, 9, 7, 7, 7, 7, 7, 7, 7, 7, 7,
0, 7, 7, 7, 7, 7, 7, 7, 7, 7, 0, 7, 7, 0, 0, 0, 0, 7, 1, 0, 0, 0, 1, 1, 1,
1 ];

)

//
============================================================================

// 3. SYNTHDEFS

// The sonification makes use of 7 SynthDefs that generate sound: 3 for
percussive sounds, 1 for the bass, 1 for the main chord, and 1 for an delay
effect. 2 extra SynthDefs are of more technical use, regulating the overall
tempo and the volume of the percussion.


// Delay effect applied on main chord FM synth
(
SynthDef(\delay, { arg inChn = 60, outChn = 0, delayL = 1, decayL = 1, delayR
= 1.1, decayR = 1.1, bpFreqL = 440, bwL = 0.5, bpFreqR = 660, bwR = 0.5,
panWidth = 0.5;
		var comboL, filterL, comboR, filterR, mixed;

		comboL = CombC.ar(In.ar(inChn, 1), delayL*2, delayL, decayL);
		filterL = BPF.ar(comboL, bpFreqL, bwL);

		comboR = CombC.ar(In.ar(inChn + 1, 1), delayR * 2, delayR,
decayR);
		filterR = BPF.ar(comboR, bpFreqR, bwR);
```

```
		mixed=Pan2.ar(filterL, 0 - panWidth) + Pan2.ar(filterR, 
panWidth);

		Out.ar(outChn, mixed);
}).add;



// Main synth using FM synthesis

SynthDef(\FMsynth, { arg outChn = 60, freq = 440, amp = 0.3, detune = 1.01, 
highpass = 250, q = 1, varSawWidth = 0.5, lowpass = 1500, lowpassQ = 0.6,
		attack = 0.3, susTime = 1, release = 1,
		fltAttack = 0.5, fltSus = 0.8, fltRelease = 0.5, depth = 1000,
		mod1 = 4.015, mod2 = 1.998, mod3 = 0.999, index1 = 500, index2 = 
500, index3 = 50;

		var env, fltEnv, freqArray, carrier, modulator1, modulator2, 
modulator3, filtered, filtered2;

		env = EnvGen.kr(Env.linen(attack, susTime, release, curve: \
welch), doneAction: 2);
		fltEnv = EnvGen.kr(Env.linen(fltAttack, fltSus, fltRelease, 
depth, curve: \welch));


		freqArray = freq * [1, detune * LFCub.kr(0.3).range(0.998, 
1.003), detune / 2*LFCub.kr(0.5).range(0.998, 1.003), detune / 4 * 
LFCub.kr(0.7).range(0.998, 1.003)]; //*LFCub.kr(0.3).range(0.998, 1.003);

		modulator1 = SinOsc.ar(freq * mod1, mul: index1);
		modulator2 = SinOsc.ar(freq * mod2, mul: index2);
		modulator3 = SinOsc.ar(freq * mod3, mul: index3);

		carrier = VarSaw.ar(freqArray+modulator1+modulator2+modulator3, 
width: varSawWidth, mul: amp) * env;
		filtered = RHPF.ar(carrier, highpass, q);

		filtered = RLPF.ar(filtered, lowpass + fltEnv, lowpassQ);

		Out.ar([0, 60], Splay.ar(filtered, 0.5))
}).add;



// Bass synth
```

```
SynthDef(\bass, {arg freq = 80, cutoff = 100, resonance = 0.1, amp = 0.45,
gate = 1, lag = 1,
              attack = 0.05, sustainTime = 1, release = 0.3,
              fltAttack = 0.05, fltSustainTime = 0.6, fltRelease = 0.2, depth
= 300;

              var env, fltEnv, snd, filter, limited;

              env = Env.linen(attack, sustainTime, release).kr(2, gate);
              fltEnv = Env.linen(fltAttack, fltSustainTime, fltRelease,
depth).kr(0, gate);

              snd = VarSaw.ar(freq/2, width: 0.5, mul: env * amp) +
VarSaw.ar([freq, freq * 0.999, freq * 1.0015], width: Rand(0.1, 0.3), mul:
env * amp);

              filter=RLPF.ar(snd, cutoff + fltEnv, resonance);

              limited=Limiter.ar(filter, 0.8);

              Out.ar(0, Splay.ar(limited, 0.5));
}).add;



// Percussive synths

SynthDef(\kickdrum, { arg amp = 0.4, oscFreq = 100, clickAmp = 0.2,
              oscAttack = 0.01, freqRelease = 0.8, oscRelease = 1, clickCutoff
= 1500;

              var freqEnv, osc, oscEnv, oscOutput, click, clickEnv,
clickOutput;

              freqEnv = EnvGen.kr(Env.perc(oscAttack, freqRelease, curve: 4),
levelScale: 0.5, levelBias: 0.5);
              osc = SinOsc.ar(oscFreq*freqEnv);
              oscEnv = Env.perc(oscAttack, oscRelease, amp).kr(2);

              click = LPF.ar(WhiteNoise.ar(clickAmp), clickCutoff);
              clickEnv = Env.perc(0.001, 0.02).kr;

              oscOutput = (osc * oscEnv);
              clickOutput = (click * clickEnv);

              Out.ar(70,
                            Pan2.ar(oscOutput + clickOutput, 0))
```

```
}).add;


SynthDef(\snaredrum, { arg volRelease = 0.6, filterRelease = 0.2, oscAmp =
0.5, amp = 0.35, oscCutoff = 1000, snapBP = 1500;

		var volEnv, filterEnv, drumOsc, drumOutput, snapOsc, snapEnv,
fullOutput;

		filterEnv = Env.perc(0.001, filterRelease).kr;
		volEnv = Env.perc(0.001, volRelease, curve: 0).kr(2);

		drumOsc = Pulse.ar(100, mul: oscAmp);
		drumOutput = LPF.ar(drumOsc, (filterEnv * oscCutoff) + 30);

		snapOsc = BPF.ar(HPF.ar(WhiteNoise.ar, 500), snapBP);
		snapEnv = Env.perc(0.001, filterRelease).kr;

		fullOutput = (drumOutput * volEnv) + (snapOsc * snapEnv);

		Out.ar(70,
				Pan2.ar(fullOutput, 0, amp)
		);
}).add;


SynthDef(\hihat, { arg amp = 0.2, attack = 0.08, release = 0.6, noiseCutoff =
6000, highpass = 2000;

		var noise, osc, oscEnv, output;

		noise = LPF.ar(WhiteNoise.ar, noiseCutoff);

		osc = HPF.ar(noise, highpass);
		oscEnv = Env.perc(attack, release, curve: -6).kr(2);

		output = (osc * oscEnv);

		Out.ar(70,
				Pan2.ar(output, 0, amp)
		);
}).add;



// Two "technical" SynthDefs, regulating overall tempo and volume on
percussion
```

```
~clockBus = Bus.control; // A control bus sending tempo values

SynthDef(\lag, { arg tempo = 100, lag = 30;

		tempo = VarLag.kr(tempo, lag, curvature: 0, warp: \lin );

		Out.kr(~clockBus, tempo);

}).add;


SynthDef(\drumMixer, { arg inChn = 70, inValue = 0.42, lag = 8;

		var volume, signal;

		inValue = inValue.varlag(lag, 0, \lin);

		volume = inValue.linlin(0.3, 0.7, 0.3, 1.5); // gives a value
between cirka 0.8 - 1.4

		signal = In.ar(inChn, 2);

		signal = signal * volume;

		Out.ar(0, signal);

}).add;
)

// =====================================================================

// 4. PATTERNS

// Definitions of patterns that plays the various Synths. The patterns are
executed/started from "fork"

~clock = TempoClock(100/60); // initiates the TempoClock for the whole piece
and sets initial BPM


// Pattern changing the overall tempo

(
~bpmPattern = {

		var bpm = Synth(\lag); var currentTempo = 100;
```

```
		100.do { arg i;

				"Year: ".post; (i+1921).postln;

				8.do { // The tempo is fetched 8 times per year =
2 times per beat

						bpm.set(\tempo, ~tempo[i]);

						0.5.wait;

						~clockBus.get({ arg y; currentTempo
= y });

//						"BPM: ".post; currentTempo.postln;
						~clock.tempo = currentTempo / 60;

				}

		}
};//.fork(~clock);


// Pettern controlling volume of percussion

~volumePattern = {

		var mixer = Synth(\drumMixer);

		100.do{ arg i;

				mixer.set(\inValue, ~danceability[i]);

				4.wait;

}};//.fork;


// Pattern playing the FM synth main chords

~chord = 0; // Starting chord C Major

~delay = Synth(\delay, [\delayL, 1.5, \decayL, 10, \bpFreqL, 2700, \bwL, 0.4,
\delayR, 1.2, \decayR, 10, \bpFreqR, 2500, \bwR, 0.2, \panWidth, 0.4]);
```

```
~mainChord = {
              100.do{ arg i;

                            var major = ~mode[i]; var minor = 1 - ~mode[i];

                            var richness = ~energy[i].linlin(0.2, 0.7, 500,
1500);

                            var resonance = ~energy[i].linlin(0.2, 0.7, 0.6,
0.1);

                            var varsaw = ~energy[i].linlin(0.2, 0.7, 0.5,
0.1);

                            var index = ~valence[i].linlin(0.37, 0.67, 300,
10);

                            var valence = ~valence[i].linlin(0.37, 0.67, 1.03,
1);

                            if( (~key[i+1] == ~key[i]) && (~key[i+2] ==
~key[i]), { ~chord = ~key[i] });

//                          "ChordNote: ".post; ~chord.postln;
//                          "Richness: ".post; richness.postln;
//                          "Valence: ".post; valence.postln;
//                          "Index: ".post; index.postln;

                            // Major chord
                            Synth(\FMsynth, [\freq, (~chord+60).midicps, \amp,
0.09 * major, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence
                            ]);
                            Synth(\FMsynth, [\freq, (~chord+64).midicps, \amp,
0.09 * major, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence
                            ]);
                            Synth(\FMsynth, [\freq, (~chord+67).midicps, \amp,
0.09 * major, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence]);
```

```
                            2.wait;

                            // Parallel minor chord
                            Synth(\FMsynth, [\freq, (~chord+57).midicps, \amp,
0.09 * minor, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence]);
                            Synth(\FMsynth, [\freq, (~chord+60).midicps, \amp,
0.09 * minor, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence]);
                            Synth(\FMsynth, [\freq, (~chord+64).midicps, \amp,
0.09 * minor, \index1, index, \index2, index, \lowpass, richness, \depth,
richness / 2, \lowpassQ, resonance, \varSawWidth, varsaw,
                                          \mod1, valence, \mod2, 2 - (valence
- 1), \mod3, 4 * valence]);

              2.wait;

              };
};




// Pattern triggering the bass synth

~bassPattern = {
              100.do { arg i;

                            // Sets the "distinctness" or "sharpness" of bass
notes depending on danceability
                            var attack = ~danceability[i].linlin(0.39, 0.68,
0.2, 0.001);
                            var release = ~danceability[i].linlin(0.39, 0.68,
0.8, 0.05);
                            var resonance = ~danceability[i].linlin(0.39,
0.68, 0.4, 0.05);

                            4.do { // 4 beats per year = 8 bass notes

                                          Synth(\bass, [\freq, (36 +
~key[i]).midicps, \amp, 0.05, \sustainTime, 0.3, \attack, attack, \release,
```

```
release, \fltAttack, attack, \fltRelease, release/1.5, \resonance,
resonance]);
                                        0.5.wait;
                                        Synth(\bass, [\freq, (48 +
~key[i]).midicps, \amp, 0.05, \sustainTime, 0.3, \attack, attack, \release,
release, \fltAttack, attack, \fltRelease, release/1.5, \resonance,
resonance]);
                                        0.5.wait;
                           }
             };
};



// Patterns triggering the various percussion sounds

~kick = {
             100.do { arg i;
                           2.do{ // One kickdrums per beat. Higher Energy
increases chance of adding extra kickdrum

                                        Synth(\kickdrum, [\oscFreq, 60, \
freqRelease, 0.4]);
                                        1.wait;
                                        Synth(\kickdrum, [\oscFreq, 60, \
freqRelease, 0.4]);
                                        0.5.wait;
                                        x = rand(1.0); if(x < ~energy[i],
{ Synth(\kickdrum, [\oscFreq, 60, \freqRelease, 0.3]); }); // Extra kick for
higher energy
                                        0.5.wait;
                           }
             }
};




~snare = {
             100.do { arg i; // One snare per beat. Additional snares added
depending on Energy. Higher Energy = more snares.

                           1.wait;
                           Synth(\snaredrum, [\oscCutoff, 1000]);
                           1.75.wait;
                           x = rand(1.0); if(x < ~energy[i], { Synth(\
snaredrum, [\oscCutoff, 1000, \amp, 0.2]); }); // extra for high energy
                           0.25.wait;
```

```
				Synth(\snaredrum, [\oscCutoff, 1000]);
				0.25.wait;
				x = rand(1.0); if(x < ~energy[i], { Synth(\
snaredrum, [\oscCutoff, 1000, \amp, 0.2]); }); // extra for high energy
				0.75.wait;
		}
};



~hihat = {
		100.do{ arg i; // Additional hihats added depending on Energy.
Higher Energy = more hihats.

				4.do{

						Synth(\hihat, [\attack, 0.01, \
release, 0.2, \amp, 0.1]);
						0.25.wait;
						if (rand(1.0) < ~energy[i], {Synth(\
hihat, [\attack, 0.01, \release, 0.15, \amp, 0.07]) });
						0.25.wait;
						Synth(\hihat, [\attack, 0.08, \
release, 0.6, \amp, 0.1]);
						0.25.wait;
						if (rand(1.0) < ~energy[i], {Synth(\
hihat, [\attack, 0.01, \release, 0.15, \amp, 0.07]) });
						0.25.wait;
				}
		}
};
)

//
=============================================================================

// 5. FORK (LAUNCHES THE SONIFICATION)

~clock = TempoClock(100/60) // Tempoclock with initial tempo of 100 BPM

(
~bpmPattern.fork(~clock);
~volumePattern.fork(~clock);
~mainChord.fork(~clock);
~bassPattern.fork(~clock);
~kick.fork(~clock);
~snare.fork(~clock);
```

```
~hihat.fork(~clock);
)
```