Sonification of High Energy Physics Data Using Live Coding and Web Based Interfaces

Konstantinos Vasilakos
Istanbul Technical University
Center for Advanced Studies in Music (MIAM)
Istanbul, Turkey
vasilakos@itu.edu.tr

Scott Wilson
University of Birmingham
Department of Music
Edgbaston, Birmingham
B15 2TT United Kingdom
s.d.wilson@bham.ac.uk

Thomas McCauley
University of Notre Dame
Department of Physics
Notre Dame, IN 46556 USA
thomas.mccauley@cern.ch

Milad Khosravi Mardakheh
University of Birmingham
Department of Music
Edgbaston, Birmingham
B15 2TT United Kingdom
MXK778@student.bham.ac.uk

Emma Margetson
University of Birmingham
Department of Music
Edgbaston, Birmingham
B15 2TT United Kingdom
EMM132@student.bham.ac.uk

Tsun Winston Yeung
University of Birmingham
Department of Music
Edgbaston, Birmingham
B15 2TT United Kingdom
TWY313@student.bham.ac.uk

ABSTRACT

This paper presents a discussion of Dark Matter, a sonification project by the Birmingham Ensemble for Electroacoustic Research (BEER), a laptop group using live coding and just-in-time programming techniques, based at the University of Birmingham (UK). The project uses prerecorded data from proton-proton collisions produced by the Large Hadron Collider (LHC) at CERN, Switzerland, and then detected and reconstructed by the Compact Muon Solenoid (CMS) experiment, and was developed with the support of the art@CMS project. Work for the Dark Matter project included the development of a custom-made environment in the SuperCollider (SC) programming language that lets the performers of the group engage in collective improvisations using dynamic interventions and networked music systems. This paper will also provide information about a spin-off project entitled the Interactive Physics Sonification System (IPSOS), an interactive and standalone online application developed in the JavaScript programming language. It provides a web-based interface that allows users to map particle data to sound on commonly used web browsers, and mobile devices, such as smartphones, tablets etc. The project was developed as an educational outreach tool to engage young students and the general public with prerecorded data derived from LHC collisions.

Author Keywords

Live Coding, Laptop Ensemble, Data Sonification, Online Sound Synthesis, Mapping Strategies, JIT Programming, SuperCollider

CCS Concepts

•**Applied computing** → **Sound and music computing;**
•**Human-centered computing** → User interface toolkits;

NIME'20, July 21-25, 2020, Royal Birmingham Conservatoire, Birmingham City University, Birmingham, United Kingdom.

1. INTRODUCTION

The Dark Matter project uses prerecorded experimental physics data from the LHC, and comprises a specialised extension of the structured live coding practices already developed by BEER. The physics data is used as raw material to build real time sonifications in a collective improvisation context employing live coding and networked music systems. It was initiated in collaboration with the art@CMS project whose main aims are to inspire and engage the general public with concepts from High-Energy Physics research.

The first part of the paper will focus on the sonification of the LHC data elaborating the live coding and collective improvisation practice from the perspective of the live coding ensemble BEER.

The second part will provide an overview of a spin-off project named IPSOS, an interface for sonification of similar data which was designed to engage the public and young students with the experimental data.

1.1 Background

Live coding is the real time modification of algorithms at run-time and involves the modification of the source code of a program that is generating sound or visuals. In other words:

> Since the computer is the instrument practised most readily by computer musicians, why not let this programming practice become the basis of new performance practice side stepping the heritage of gestural acoustic instruments? Live coding provides an alternative opportunity to keep the human being involved in live electronic music.[9]

It is a performance paradigm in electronic music and time-based arts, and has formed the central practice of a number of artistic communities in recent years, such as Toplap.org (`https://toplap.org/`) or the Algorave community (`https://algorave.com/`). The latter group focuses on the EDM and IDM genres, but is generally oriented towards repetitive beat-based music for dance floors. Usually the audience can witness the manipulation of the code in conjunction with visuals that are running in the background. Live coding has also been at the core of research activities of many laptop ensembles that focus on collective improvisation and networked performance (not to be confused with telematic performance). Some of these are PowerBooks Unplugged, the Cybernetic Orchestra, the Istanbul Coding Ensemble (ICE) and BEER.

One of the aims of BEER is to investigate strategies for creating musical form using networked systems in order to build collective improvisations [13]. The ensemble uses custom-made software in order to enact real time communication, data sharing, and synchronization amongst the performers often using software resources, such as shared clocks that allow one to schedule event streams of sound synthesis control instructions based on a master tempo rate. Much of this has been developed within the Utopia library (`https://github.com/muellmusik/Utopia`) for the SuperCollider language (`https://supercollider.github.io/`).

1.2 Data Sonification

Data sonification is the process of synthesizing sound using any sort of data that was obtained by scientific or non-scientific activities, for example, environmental and forecast information to metro routes and geomagnetic fields and solar activity. A thorough discussion of sonification is beyond the scope of this paper. A concise explanation however is provided in The Sonification Handbook:

> Sonification is a core component of an auditory display: the technique of rendering sound in response to data and interactions.[7]

The terms sonification and auditory display are widely used to describe the process of using sound events to convey a message of change in the state of a running process or detect activity of a system. In the digital domain, continuous signal flows or compiled data can be deployed interactively to fluctuate the control parameters of sound synthesis or it may be converted to render a waveform (Non Real Time composition). Thus, evidently, sonification holds a significant place in the (Sound/Sonic) arts landscape. However, the authors of this paper share the idea that if one wants to create musically interesting sonification results human intervention in the form of aesthetic choice is necessary. That is to say that using the data as is, for example, in a one-to-one mapping relationship of data to sound, for example, rendering data as audio samples (often called audification) would be a clear consistent but not necessarily musically appealing approach. Given this choice to allow aesthetic intervention, the sonic result is heavily dependent on the mapping strategies chosen and the decision made when constructing the rendering system. Of course this is mostly welcomed, as this sort of creative exploration is commonplace in Electroacoustic music composition and related art forms. Similarly, human choice affords us the possibility to highlight salient aspects of the data, making sonifications less arbitrary and more relevant and meaningful within the context of the domain being explored. Alberto de Campo's remark about sonification highlights the importance of this methodology as providing a medium to bring together two distinctive worlds, that is art and science:

> For the sonic arts, sonification brings about curiosity toward the origins of sounds and toward a broader cultural and social context. Perhaps sonification is for sound art what documentary is for film. Certainly it is an area open for explorations, full of inspiration and potential insights for sciences and arts.[6]

. Some examples of how sonification has been used in a musical way include Mark Ballora's plentiful projects, to name but a few, *Sonifications of Heart Rate Variability (HRV) data* (2000), *The Mickey Heart Band - Mysterium Tremendum* (2012), *Sonifications of Antarctic Ice Data* (2014); Alberto de Campo and Daye's *Navegar and Terra Nullius* (2006); and the *Giant Leaps* (2019) project by Andrew Santaguida, Matt Russo and Dan Tamayo [10], which uses data from the National Aeronautics and Space Administration. Additional examples of similarities in approach include the *Quantizer* [8], and Lily Asquith's project on sonifying physics data from the ATLAS project [1].

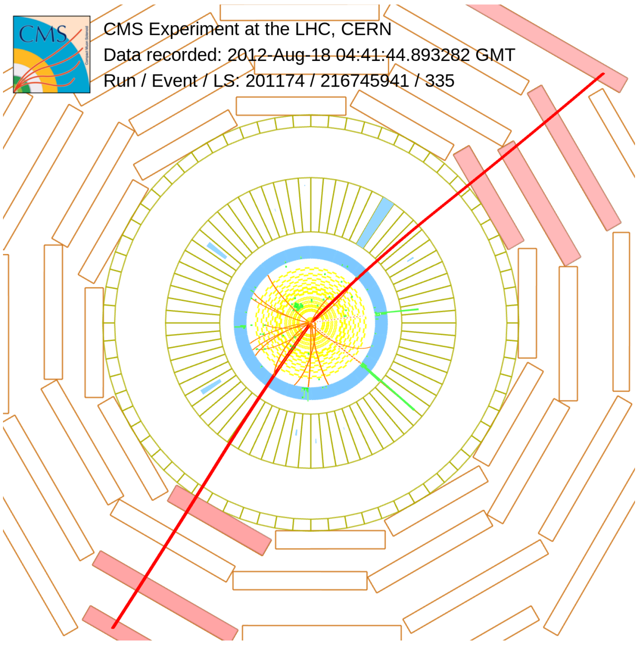

Figure 1: Visualization of an event in the CMS detector. Data from such an event is used as input for sonification.

1.3 Data from the CMS Experiment

The CMS Experiment at the LHC at CERN [2] is a large particle physics experiment probing the behavior of elementary particles and interactions and looking for new physics beyond what is known as the Standard Model of Particle Physics. To date perhaps the most famous result has been the discovery of the Higgs boson[3].

The CMS detector can be described as a 100 megapixel digital camera which takes 40 million pictures per second. An "event" is a snapshot taken when bunches of protons collide coming from opposite directions, triggering a "picture" to be taken. Often in the events an unstable, unseen particle (such as a Z boson) is produced which decays into more stable particles (such as electrons or muons) which are detected. Reconstructing these particles allows one to discern and study what produced them. "Reconstruction" means we determine and measure the properties of the particles, such as their momentum, direction, and mass.

Figure 1 is a view of one event detected by CMS looking along the beam pipe through which the protons travel and collide in the center of the detector. This event displays characteristics consistent with production of a Higgs boson which decays into two Z bosons. The two long red lines represent the reconstructed trajectories of two muons produced from the decay of one Z boson. The light green lines and rectangles represent the reconstructed trajectories of two electrons produced from the decay of the other Z boson.

In practice the proton-proton collisions produced by the LHC produce many more collision events in CMS than can be recorded. In order to reduce the amount of data recorded but at the same time keeping potentially interesting events CMS filters the incoming data, using a complex scheme of trigger conditions. The Dark Matter project (described in Section 2) uses data with events from the particle collisions from one set of trigger conditions or "stream". This was primarily suggested by Maurizio Pierini, a physicist from CMS who prepared and made available the data files. They include approximately 60k events containing information about muons and jets, which are "sprays" of particles produced by quarks and gluons.

A snippet of a data file is as follows:

```
{
  "event": {
    "eventNum": 1257757925,
    "muons": [],
    "jets": [
      {
        "pt": 241.145,
        "eta": -1.76472,
        "phi": -0.213645,
        "m": 18.0604,
        "constituents": [
          {
            "pt": 135.41,
            "eta": -1.7725,
            "phi": -0.218491,
            "m": 0.0000053948
          }]}]}}
```

Kinematic properties such as the transverse momentum "pt" , the pseudo-rapidity "eta", and "phi" angle of the particle or jet are found in the data. A description of these parameters can be found here [11].

Along with the scientific results the data collected comprise a large part of the scientific legacy of CMS. In recognition of this legacy, and of the benefits of the data to public education and engagement, CMS has drafted, adopted, and carried out a data preservation and open-access policy [4]. Part of this open-access policy is to release data to the public domain. Part of this data has been used in this project for IPSOS (described in Section 4). Data of a similar format shown above was produced from events containing candidate Z and Higgs bosons.

2. THE DARK MATTER PROJECT

One of the aims of the project was to explore the data in terms of its musical viability in the context of electronic music improvisation. The connection of these two different areas of sonic arts highlights the intersection of diverse techniques and blurring methodologies, that is, programming, live coding and sonification. Mike Vaughan [12] specifically highlights the hybridization of diverse skills that take place in the project:

> A third distinct category is one where the technology of production or dissemination is itself more central to the artistic pursuit: for example, works that focus on the sonification of data streams, and 'live-coding', which (arguably) represents a hybridization of programming and musical skills in the context of improvisation. This improvisation may also be shaped by global decisions regarding its structure, or by predetermining the musical material to be explored.

Live coding seemed to be the most ideal way to explore the data. As it allows one to experiment freely and to investigate the data at a microscopic level but also to interpret it

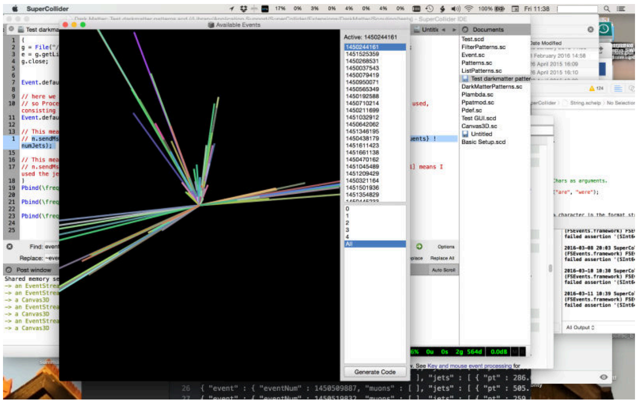

Figure 2: Selection Interface and Visualisation for Live Coding.

in many ways without being constrained by fixed mechanics ingrained in the performing system. For example, following the approach of changing the mapping of a particle's data and connecting it into another control parameter dynamically. This way the system is more powerful and flexible during improvisation, allowing one to take decisions at the same time as building the interaction capabilities of the environment. This could be also reflected in the concept of *kairotic coding* [5], which seems to be at the core of the ethos of most live coding methodology. Kairotic is an interesting concept when applied to live coding. Considering the etymology of *kairos* derived from Greek, it freely translates as the optimal moment to act upon a situation or take a certain decision at one's own will; thus, it interestingly highlights the improvisatory and dynamic intervention taken into the musical outcome as well as the constant introspection and decision making regarding the structure of a running system, offering an impressive array of interaction affordances in a digital environment. Therefore, live coding provided us with the best methodology to explore the data and its musical viability.

3. TECHNICAL OVERVIEW

3.1 Dark Matter Platform in SC

The system is entirely developed in the SuperCollider (SC) programming language. It is the ensemble's platform of choice for live coding, as it provides a state-of-the-art sound synthesis server and an integrated interpreter for code execution and manipulation in real time. The ensemble is using Utopia, a programming library for SC that lets the performers establish synchronization and real time communication during the performance.

Initially, we designed a system in SC that allowed us to parse and assign the data from a JSON file including the particle data. The file consists of a series of collision events, each describing the post-collision properties of a number of sub-atomic particles. Initially, we render the particles' arrays into an SC dictionary, derived from the original static JSON file which is stored on the hard drive of each user's computer.

3.2 The Dark Matter Interface

The program provides an interface (Figure 2) that allows basic functionality such as selecting the event to be sonified, and viewing information about the different particles and jets therein. The interface also provides a visualization window of the selected event showing the collisions and the selected particles.

3.3 Control and Interaction

Work also included the development of a series of custom made patterns for SC, the most important of which are Pjet and Pconstituent, which allow you to access the data for a particular jet or particle respectively. In addition to these versions which provided the 'raw' values, we also added normalised variants which scaled the range of values within the event to between 0.0 to 1.0 on a parameter by parameter basis, e.g. PjetS and PconstituentS. This allowed for predictable input ranges when scaling to an appropriate range for a synthesis parameter. Patterns in SC provide a convenient way to interact with synthesizers in real time, allowing variation of the control parameters of a synthesiser without interrupting the sound generation during the performance. A pattern is a template for a stream of values. SC examples include Pseq, Prand, Pser, Pgeom etc.. 'Event patterns' such as Pbind (not to be confused with particle collision events) allow one to bind value streams to sequences of synthesis 'events', i.e. notes or parameter changes. In addition, these classes offer a high level interface to start and stop the streams on a given interval, as well as bind the sequence to a user-defined synchronization clock in the SC program. Proxy classes, such as Pdef and Pdefn, afford the possibility to redefine streams while they are running. Once the patterns are defined and running, the performer is thus able to map data streams to any control input of a synthesizer and control mapping and scaling dynamically. Similarly, changing the active event from the selection window results in the currently running algorithm continuing with the new input data, allowing comparison and contrast of different physics events.

Once these are defined inside a Pbind, then the data is tapped into the control parameters of the synths, for example a mapping between one aspect of a particle's data and the frequency of an oscillator. It would be pointless to describe all the potential mappings and their effects, as the options are vast, and the result is highly dependant on the impromptu mapping strategies adopted during improvisation, and the availability of the control parameters in a given synthesis algorithm in use at any given point in the performance.

The importance of parameter mapping while designing digital environments is broadly explored in the NIME community and thus it would be a bit redundant to stress its merits in this paper. In aid of this approach we adopted several scaling functions which were used to apply ranges for each stream in order to create efficient mapping strategies, mostly refined experimentally following a trial and error approach during improvisation with one's synths at hand.

While the performance strategy is as straightforward as a parameter mapping improvisation, there is no complicated structure that the performers have to follow. This makes the project more accessible for performance by other live coding ensembles, such as the ICE. However, the music that is created remains unpredictable over subsequent performances even when using the same source of data. It provides vast possibilities for mapping, and while the sonic outcome is dependent on the arbitrary possibilities of combining sound synthesis modules on the fly (and/or prepared in advance) it creates a unique sonic outcome that we have personally found both scientifically interesting and musically meaningful.

3.4 Visualization

In addition to the sonic elements of the work, real time visualisations were developed in the Processing (`https://processing.org/`) language by Yeung and Wilson. Communication from SC was accomplished via the Open Sound Control (OSC) protocol, allowing the various visualisations to reflect which physics event and individual components were being sonified by each performer, in addition to projecting executed code in keeping with the common practice within the live coding community. Figure 3 illustrates a scene from the vizualisations.

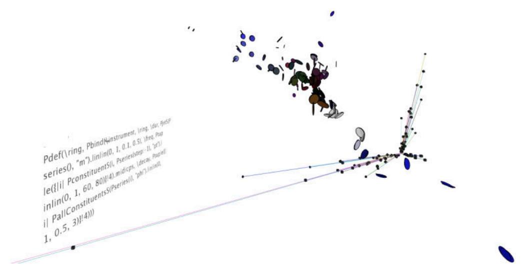

Figure 3: Visualization Scene from Dark Matter.

4. IPSOS

IPSOS is a sonification interface using similar data sets but with interaction taking place via a front-end interface in web browsers rather than via a coding interface. Figure 4 shows the interface of the app.

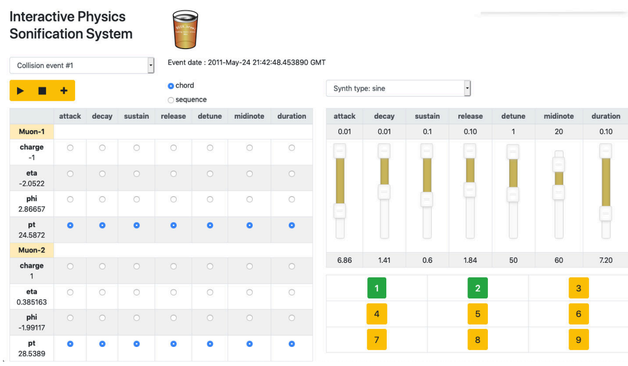

Figure 4: IPSOS Front-End Web Interface.

It is a web-based application that runs on any modern computer or mobile device without any dependencies or pre-installed third party applications. The platform provides a real time sound synthesis engine and an interface for interactive exploration of the data, allowing users to create their own data sonifications and musical improvisations in real time. It can be used by those with a non-technical background and with minimum effort and knowledge on sound design techniques or physics. Our initial motivation was to create an interface suitable for workshops with school age children, but the approach has proved robust and flexible enough to bring the creative possibilities of the Dark Matter approach to a wide array of participants of different ages. An accompanying website - developed primarily by Mardakheh and Margetson - provides instruction and substantial background information. As such it provides the possibility for a range of users to expand their knowledge of both particle physics and basic sound synthesis in a creative environment. The app provides some basic control manipulation, including faders and toggle buttons to control the sound synthesis oscillators. IPSOS is a progressive and modern web-app using libraries such as Tone.js for the sound generation, and Bootstrap as the front-end framework. It is developed using the Meteor platform and the JavaScript programming language. The code repository of the project can be found at this link https://github.com/KonVas/Ipsosboard To visit the application follow this link `http://ipsos.web.cern.ch/`

4.1 Sound Engine of IPSOS

The interface provides a real time synthesis engine that offers an array of sound oscillators synthesizing classic synthesis waveforms, such as sine, square, triangle, and sawtooth. The user is able to select one of these and fluctuate its basic sound synthesis parameters. The system provides basic control parameters of the oscillators such as pitch and detune, and a basic ADSR manipulation. The control of the parameters is explained thoroughly in the next section.

4.2 Control and Interaction with IPSOS

The system uses a file which is stored in the app's resources folder with data from events, as in the live coding version of the project. The selection of the data is similarly done on an event basis using the event's ID number. The user is able to load an event using a pop-up window which offers all the events separately as shown on the figure above. The system also provides information about the date and time of the event following this format: "Event date: 2012-May-28 08:01:20.141735 GMT".

The user is able to load an event provided by the file as seen on Figure 4. Once the event is selected all values appear on the matrix table which is implemented in order to host the mapping between the data and synthesis parameters of the sound generators as seen in Figure 5. The user can make arbitrary associations with the data and sound controls from the selected event and store it as a preset, pressing the [+] button next to the play button on top left of the interface. Each preset is assigned one of the numbered boxes at the right bottom. Once a new preset is stored pressing the plus button it will be allocated to the next available box; currently the platform offers nine preset slots. The idea is to use these as sequences of short motifs and play them in a sequence or in a random order building a kind of a form of the musical improvisation. The particles can be sonified as either a chord or a sequence. The platform also provides a system where the mappings can be transposed to a different range using two dimensional range faders, as shown on the top right of the interface. Each slider has two values altering the minimum and maximum values of the range of the scaling function. Using these faders the user can adjust the values to more appropriate ranges while interacting with the application. For each sound parameter including the ADSR controls there is one slider, making the system very flexible in terms of range specification.

The online app has proven to be a useful tool for educational purposes, helping to raise the awareness on electronic music and sound design nuances as well as exposing the users to new physics using music and sound, arguably one of the most accessible concepts. People with diverse skills and technical or non-technical backgrounds can interact with the application and create some basic audio interpretations of the data, which can be used for making simple musical structures and small improvised pieces.

5. DISSEMINATION, SPIN OFFS AND FUTURE DIRECTIONS

The project in its various aspects has been presented internationally, with performances in the U.K., Canada, France, Colombia, Mexico, Turkey and Greece, as well as at CERN itself, to a variety of audiences ranging from professional physicists, through artists and students, to the public at large. IPSOS and Dark Matter workshops have taken place in Toronto (Ontario Science Centre), Llangefni, the Attenborough Centre, Aberdeen University, Durham University, Istanbul Technical University, Bilgi University, Bilkent University, Sabanci University in Turkey and at the Creations Conference in Athens, to participants including both students and teachers, and ranging in age from adults to 11 year old children. In addition to IPSOS, other spin-offs have taken place or are planned. An eponymous work for orchestra, electroacoustics and video was premiered by the Esprit Orchestra in 2018, and a new spin-off is in development, aiming to combine our existing approaches with real time generated notation for instrumental performers.

	attack	decay	sustain	release	detune	midinote	duration
Electron-1							
charge 1	●	○	○	○	●	○	○
eta -0.733802	○	○	●	○	○	○	○
phi 0.205827	○	○	○	●	○	○	●
pt 41.79	○	●	○	○	○	●	○
Electron-2							
charge -1	○	○	○	○	○	●	○
eta -1.79903	●	○	●	○	○	○	○
phi -2.47459	○	○	○	○	●	○	●
pt 40.4004	○	●	○	●	○	○	○

Figure 5: IPSOS Mapping Table.

6. CONCLUSION

Dark Matter is an interdisciplinary project hybridizing diverse fields within physics and music, deploying two different approaches from within the electroacoustic and experimental music research landscape, that is live coding and sonification, and at the same time it is contributing to the ongoing dialogue between art and science. Similarly, IPSOS attempts to create a new and engaging way of educating the general public about advanced concepts of physics and at the same time offers a tool to create musical interpretations of high-energy physics data.

7. ACKNOWLEDGMENTS

Our thanks to Maurizio Pierini (CMS, CERN), Michael Hoch and Angelos Alexopoulos (art@CMS, CERN). We wish also to acknowledge the contributions of the various members of BEER, particularly Winston Yeung, Emma Margeston, and Luca Danieli who in addition to the contributions noted above, road tested various aspects of the project, and made small contributions or suggestions in the development of some of the SuperCollider and visualisation resources. IPSOS was developed with the financial support of the University of Birmingham (UK) and art@CMS at CERN in Switzerland.

8. REFERENCES

[1] L. Asquith. Listening to data from the Large Hadron Collider | Lily Asquith |TEDxZurich.

[2] S. Chatrchyan et al. The CMS Experiment at the CERN LHC. *JINST*, 3:S08004, 2008.

[3] S. Chatrchyan et al. Observation of a New Boson at a Mass of 125 GeV with the CMS Experiment at the LHC. *Phys. Lett.*, B716:30–61, 2012.

[4] CMS Collaboration. 2018 CMS data preservation, re-use and open access policy, 2018.

[5] E. Cocker. What now, what next- *kairotic* coding and the unfolding future seized. *Digital Creativity*, 29(1):82–95, Jan. 2018.

[6] A. de Campo, J. Rohrhuber, T. Bovermann, and C. Frauenberger. Sonification and auditory display in supercollider. In S. Wilson, D. Cottle, and N. Collins, editors, *The SuperCollider Book*. The MIT Press, Cambridge, MA US, 2011.

[7] T. Hermann, A. Huntt, and J. G. Neuhoff. Auditory display and sonification. In T. Hermann, A. Huntt, and J. G. Neuhoff, editors, *The Sonification Handbook*. Logos Publishing House, Berlin, Germany, 2011.

[8] E. Hill, J. Cherston, S. Goldfarb, and J. Paradiso. ATLAS data sonification : a new interface for musical expression. In *Proceedings of 38th International Conference on High Energy Physics - PoS(ICHEP2016)*, page 1042, Chicago, USA, Feb. 2017. Sissa Medialab.

[9] C. Nilson. Live coding practice. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, NIME '07, pages 112–117, New York, NY, USA, 2007. Association for Computing Machinery.

[10] M. Sosby. Data and Music: What 50 Years of Exploring Our Moon Sounds Like, July 2019.

[11] M. Tanabashi et al. Review of Particle Physics. *Phys. Rev.*, D98(3):030001, 2018.

[12] M. Vaughan. Register, Dialect, Convolution, and 'Crosstalk': Reflections on '...the Zones of Influence and Hybridity Between Electroacoustic, Acousmatique Music, Techno, and IDM'. *Contemporary Music Review*, 35(2):166–183, Mar. 2016.

[13] S. Wilson, N. Lorway, R. Coull, K. Vasilakos, and T. Moyers. Free as in beer: Some explorations into structured improvisation using networked live-coding systems. *Computer Music Journal*, 38(1):54–64, 2014.