Signal to Noise Loops

A Cybernetic Approach to Musical Performance with Smart City Data and Generative Music Techniques

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ABSTRACT

This article introduces the *Signal to Noise Loops* project, which consisted of a series of performances and installations that took place worldwide between 2017 and 2022. The project utilized open data from a network of Internet of Things sensors placed around Dublin, Ireland, in the context of experimental music performance and composition. This network was underpinned by a theoretical framework from the field of cybernetics that united and integrated methods and approaches from the wide-ranging fields of data-driven music, generative music, rhythm analysis, and smart cities research.

THE *SIGNAL TO NOISE LOOPS* PROJECT

In the *Signal to Noise Loops* project, I integrated open data from a series of Internet of Things (IoT) sensor networks in Dublin, Ireland, into a series of experimental music performances and installations that treat the city, represented in the data, as a musical collaborator. I created a data-driven generative music system to help realize the project, adapting and expanding it as the project proceeded. In developing the initial design, I was inspired by methods and concepts from the field of cybernetics, which provided a useful framework for producing the works.

OVERVIEW OF CYBERNETICS

In 1948, mathematician Norbert Wiener introduced the field of cybernetics, defining it as the scientific study of control and communication in the animal and the machine [1]. He drew comparisons between self-regulation and self-correction across electronic, mechanical, and biological systems. Von Foerster began to integrate the observer into the cybernetic system, introducing the key cybernetic concept of reflexivity [2]. This approach was extended in Maturana and Varela's work on self-organization [3]. Beer would redefine the field as "the science of effective organization" [4], proposing his influential viable system model [5]. Beer opened up the world of cybernetics, extending cybernetic thought to political theory, management science, and the arts.

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TOWARD A CYBERNETIC MUSIC

Dunbar-Hester discusses the impact of cybernetics on experimental music from 1950 to 1980 [6], commenting that approaches in this period seem roughly consonant with Hayles's conception of "second wave," or second-order, cybernetics [7]. First-order cybernetics is concerned with homeostasis through corrective feedback. Second-order cybernetics embraces change and evolution, integrating the observer into the system to create reflexive, human-in-the-loop systems.

Pickles presents a nuanced analysis that casts Louis and Bebe Barron, Herbert Brün, Alvin Lucier, and Roland Kayn as key contributors to first-order cybernetic music; he describes composers Brian Eno and Agostino Di Scipio as producing second-order cybernetic music [8]. Eno calls his approach "generative music," defining it as "system-propagated music that is in a state of constant flux." These systems (e.g. *Discreet Music* and *Music for Airports*) are driven by phase-shifting looping processes similar to those exhibited in the work of Steve Reich. Reich's work receives a similar cybernetic analysis from Strange [9]. Lucier's 1965 *Music for Solo Performer*, categorized by Pickles as first-order cybernetics, takes a different approach [10]. In the piece, Lucier employs data-driven music composition techniques to map brainwave data to control musical parameters, specifically percussion patterns. Drawing from these influences, I explored generative music systems, phase-shifted looping, and data-driven music in the *Signal to Noise Loops* project.

SIGNAL-TO-NOISE RATIO

Third-order cybernetics privileges emergence: the appearance of behaviors, patterns, and properties that are not apparent in the isolated parts of a system but emerge when the parts interact as a whole. Emergence is at play in William Basinski's 2001 work *The Disintegration Loops*.

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While Basinski was digitizing some analog tape loops, the tapes in question began to deteriorate. This led to the emergence of a highly novel sonic result in the digital capture [11]. The original musical signal is increasingly lost against a background of noise that expands as the tape degrades. This, in turn, recalls the concept of signal-to-noise ratio (S/N). In information theory, S/N is used to quantify the strength of a signal against its background noise. In IoT networks, a high S/N is favorable, but in *The Disintegration Loops*, the listener hears novel musical materials emerge as the S/N decreases with each loop. This relationship between the perceived S/N of a sonic signal and the emergence of novel aesthetic patterns informed the trajectory of Basinski's work.

SMART CITIES

Smart cities are urban spaces that use Internet of Things (IoT)-sensing technologies to collect data that can be used to organize life in the city and aid in accomplishing civic goals related to management, governance, and policymaking [12,13]. While in theory, this should have a positive impact on the quality of life for urban citizens, this is not always the case [14].

Dublin, Ireland, runs a variety of smart city projects, providing access to open data from a series of sensor networks around the city [15]. Parallels exist between smart cities and cybernetic systems in terms of both the self-organizing dynamics at play and the use of feedback loops to drive goal-seeking behaviors [16,17]. Deriving from Henri Lefebvre's rhythmanalysis, the concept of rhythmicity has become a crucial theoretical tool for making sense of the complex big data flows of the modern smart city, allowing researchers to understand urban environments in terms of Lefebvre's categories of rhythmic alignments [18,19]. This application of Lefebvre's theory within a wider cybernetic framework provided me with a useful lens through which to approach the use of smart city data in a data-driven music context.

Mattern argues that thinking of cities as rationally ordered and programmable computers conceals the messiness of urban life and the myriad forms of urban intelligence that are irreducible to digital information [20]. Instead, she asks us to consider why our cities have become increasingly pervaded with networks of sensing devices—and whose interests the harvested data might serve.

Artists and researchers studying the Internet of Musical Things [21], and Musical Smart Cities more specifically [22], have begun a process of appropriating these technologies and the data they collect to serve musical purposes. In the *Signal to Noise Loops* project, I aimed to achieve something similar within an overarching cybernetic framework. To help to address privacy concerns, I used only publicly available, GDPR-compliant, open data in which the privacy of the individual is secure [23]. Most of this data is provided by Smart Dublin's open data store, Dublinked, and is accessible through a series of APIs and/or data stores [24,25]. I obtained additional data for the project from Transport Infrastructure Ireland (TII), Ireland's Open Data Portal, and OpenWeatherMap [26–28].

ITERATION 1: EVOLVING FEEDBACK LOOPS, CELLULAR AUTOMATA, AND DIRECT MAPPING

My first performance of the project was *Noise Loops for Laptop, Improvised Electric Guitar and Dublin City Noise Data* at the 2017 Sonic Dreams Festival in Waterford, Ireland [29]. I used noise data from a series of sensors around Dublin to drive a performance system I created with Python, Max for Live, and Ableton Live (Fig. 1). At the outset of each performance, I downloaded the most up-to-date data archives and stored them locally for the duration of the performance. The system explored the cybernetic ideas of looping, human-in-the-loop reflexivity, and evolution. It allowed me, as the performer, to record loops of improvised guitar passages live. The system then manipulated these loops through phase shifting, buffer

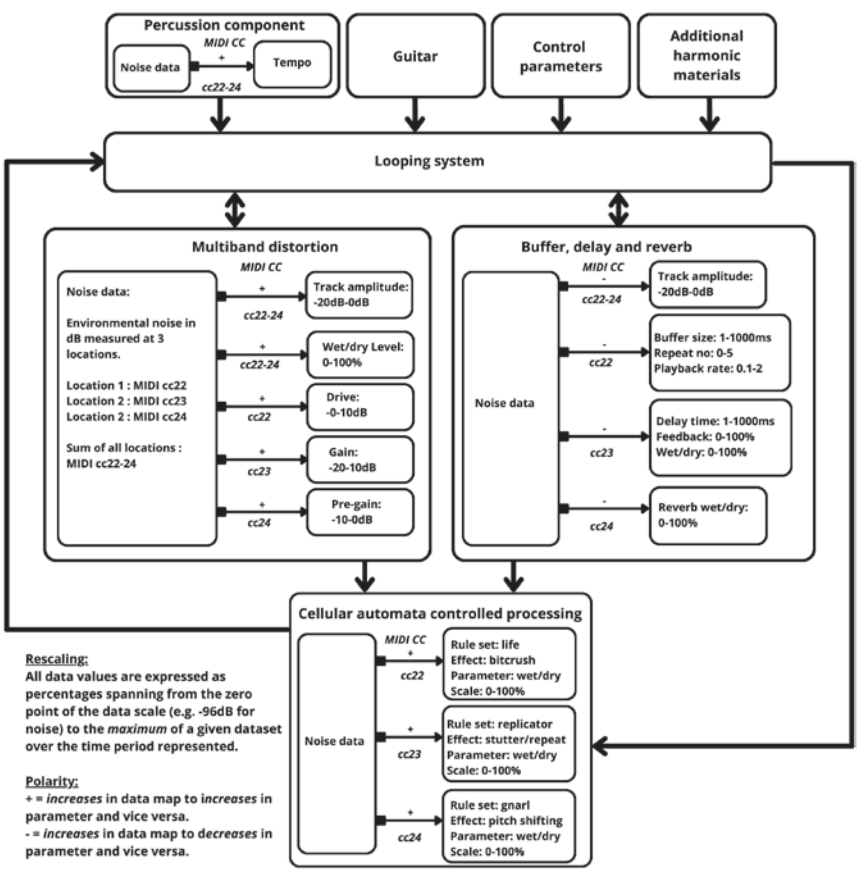

Fig. 1. Overview of Iteration 1 with data-to-sound mapping strategies. (© Stephen Roddy)

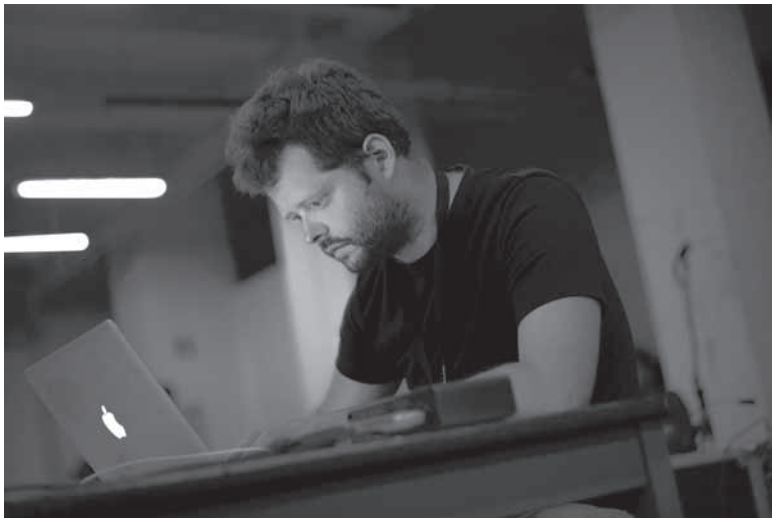

Fig. 2. Performing *Signal to Noise Loops i++: Noise, Water, Air* at xCoAx 2018. (© Miguel Carvalhais)

manipulation, and signal processing techniques controlled by the environmental noise data.

Drawing from the concept of change, I set up the system to use cellular automata (CA) to organize sonic content at the textural and timbral levels, while I, the performer, would provide rhythmic, melodic, and harmonic materials. I used a variety of rule sets (including Conway's Life, Replicator by Fredkin, and Gnarl by Evans and Serviettes) to control the application of buffer effects, pitch modulation, and distortion.

The overall noise levels at different monitors around the city determine the degree to which these processes are applied. Alongside the CA component, the state of the city as represented in the noise data directly determined a series of sonic parameters at the timbral, textural, and macro-organizational levels throughout a given performance. For example, informed by the concept of S/N, the data were mapped to directly control the timbral quality of the overall piece via the application of reverb and multiband distortion across the mix; as noise across the city increases, so too does the distortion. The tempo of the percussive component was controlled by the noise data so that increases in dB led to a higher tempo.

ITERATION 2: GENERATIVE SYSTEMS, MUSICAL INTERACTIONS, AND RICHER DATA

The next performance with the system titled *Signal to Noise Loops i++: Noise, Water, Air* took place at xCoAx 2018 in Madrid (Fig. 2) [30]. I made a series of changes to the system before the performance, introducing new data sources—air pollution and water level measures—alongside the original noise data. This allowed the performance to exploit the abnormal sequence of weather phenomena that occurred in the city in the first quarter of 2018 [31].

The introduction of further streams of data allowed for the appearance, through contrast and comparison, of what Lefebvre terms arrhythmic and polyrhythmic patterns, the linear cyclic patterns of urban activity defined by conflict or dissonance between rhythmic patterns (arrhythmia) or coexistence without conflict between patterns (polyrhythmia), respectively [32]. To explore these cyclic structures, I expanded the system to allow data to be input at a variety of user-defined rates/speeds. For example, the flow of people into the city each morning and back out to the suburbs in the evening provided one such cyclical pattern. As inclement weather conditions prevailed, these traffic patterns would be interrupted, resulting in deviations in the air quality and noise levels around the town. Water levels provided a more direct indication of precipitation patterns.

The capacity for recording musical patterns and manipulating them in live feedback loops remained, but the mode of musical performance and interaction was changed. I removed the electric guitar in favor of improvised electronic music. I used Liine's Lemur app for iOS to control synthesis routines in Native Instrument's Reaktor and the Ableton Live Wavetable Synth. I also set up Reaktor to run patches employing a mixture of additive and subtractive synthesis techniques to generate data-driven rhythmic materials. This approach opened up a wealth of possibilities for mapping the data to sonic parameters and for generating musical materials at the level of the individual object/note/event within a given musical pattern.

I introduced a data-driven stochastic process to generate semi-random musical patterns. The operation of this generative procedure was constrained by two decision-making loops. The first loop, presented in Fig. 3, monitored the input of the performer and made decisions about how to respond, changing and evolving its response as the inputs changed. The second, presented in Fig. 4, monitored the smart city data and made changes to the musical patterns input by the performer at the note level and the sound synthesis and effects levels. When the chaotic weather patterns emerged in the data, the system disregarded the performer's input completely, replacing it instead with harsh-sounding, procedurally generated harmonic materials driven by the data. Outside of this, it embellished and complemented the performance.

ITERATION 3: TOWARD EMERGENCE THROUGH EURYTHMIA

A third performance took place during the concert for the 2018 conference on Computer Simulation of Musical Creativity in Dublin, and a fourth performance took place at ISSTA 2018, the festival of the Irish Sound Science and Technology Association in Derry/Londonderry [33,34]. Figure 5 describes the data-to-sound mappings used for these performances. I used data from periods in which a series of demonstrations in support of expanded reproductive rights and fairer housing policies were taking place in Dublin. I created a third iteration of the system that added new data sources: pedestrian and vehicular traffic flow, weather data, and emergency warnings.

My intention in introducing further data sources was to give over even more control to the city, allowing it to define

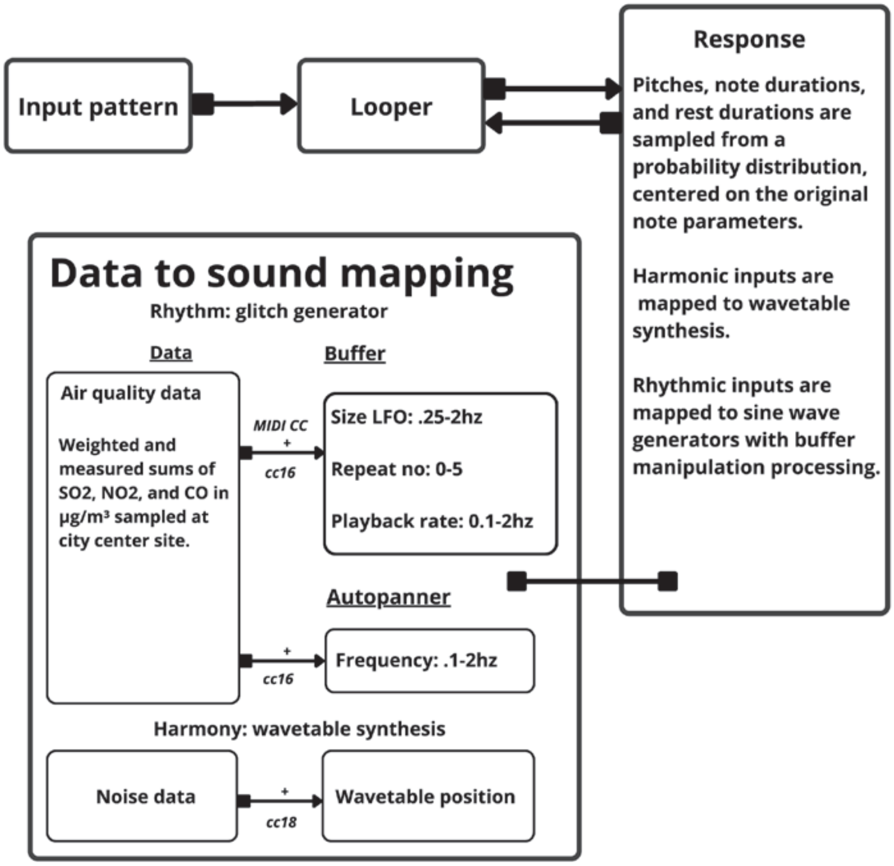

Fig. 3. Decision Loop A with data-to-sound-mapping strategies. (© Stephen Roddy)

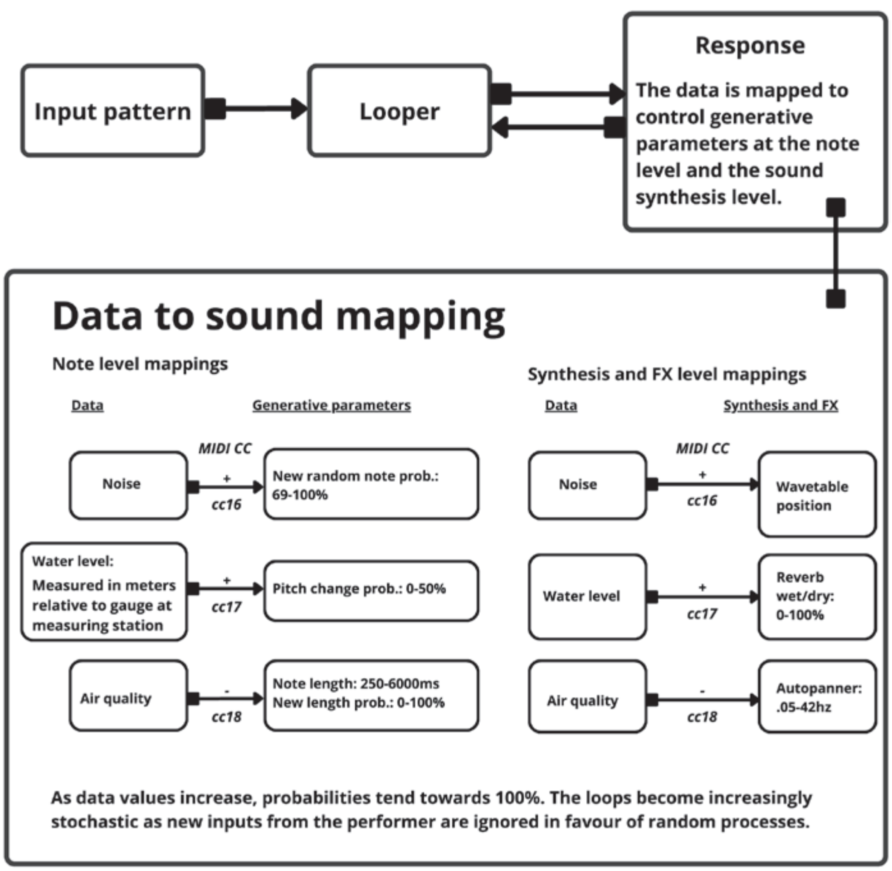

Fig. 4. Decision Loop B with data-to-sound-mapping strategies. (© Stephen Roddy)

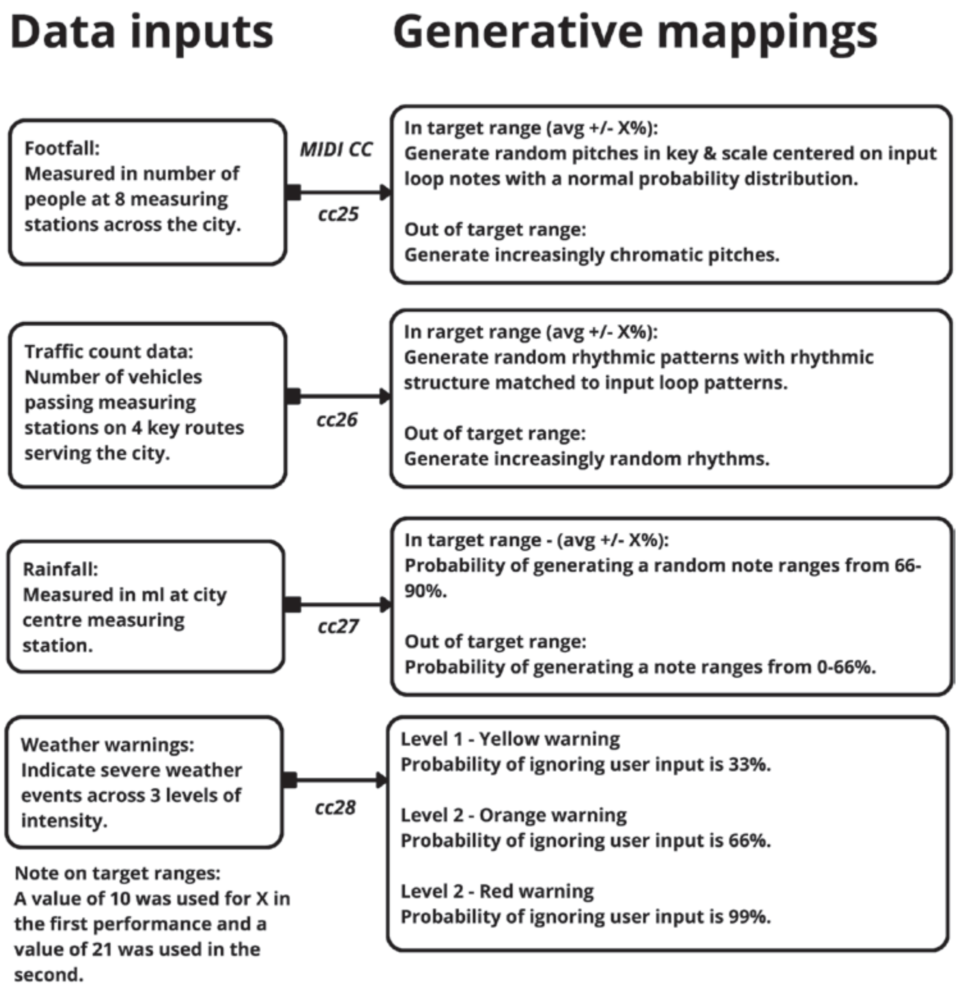

Fig. 5. Overview of Iteration 3 with data-to-sound-mapping strategies. (© Stephen Roddy)

increasingly larger portions of each performance. As the human performer, I still inputted improvised musical patterns, but improvisations are treated as a starting point by the system, which always evolves, mutates, and iterates over the performer's input. Exactly how that happens is determined once again by the data, but the key concept driving proceedings here is that of eurhythmia, a Lefebvrian rhythmic category describing constructive interaction between multiple rhythms. By integrating additional smart city data sources into the decision-making loops, I created an opportunity for the cybernetic emergence of novel aesthetic patterns through a process of eurhythmia. In essence, when the data fall within data-specific target ranges, the decision loops build and elaborate upon the performer's (my) input in a constructive manner. When the data fall out of these target ranges, the loops make dissonant musical choices to reflect the arrhythmic patterns present in the source data. Both conditions result in the emergence of novel aesthetic patterns, albeit with vastly different sonic results.

ITERATION 4: COVID-19 CRISIS RESPONSE AND THE FULLY AUTOMATED SYSTEM

As I began work on the fourth iteration of the system, the COVID-19 crisis took hold. I chose to address the impact of the pandemic on Dublin by spotlighting the city as the sole musical performer, taking myself entirely out of the performance. I had been increasingly ceding control throughout the project and now looked for a way to remove myself fully as a performer and allow the city to speak for itself. The system would become the musical instrument, and Dublin would act as both the instrumentalist and the tune, while I would take a back seat, acting as an organizer and supervisor during the creative process. An overview of this iteration is presented in Fig. 6.

I introduced two machine learning tools developed by the Magenta project to achieve these goals. "Continue" uses a recurrent neural network (RNN) architecture to create musical passages based on previous inputs, and "Interpolate" uses a variational autoencoder trained on the MAESTRO data set to produce permutations between two input melodic sequences [35]. The data-driven generative music component of the system generated the input sequences for both components. The degree to which these musical materials mutate and evolve is driven by the data.

I adapted the project for an online mode of expression to safely continue performances during the pandemic. This involved moving away from live performance and toward an audiovisual mode of presentation. I returned to the initial noise data with which the project had begun and selected data representing the city both before and during the crisis. The role and implications of noise and S/N in the project changed drastically with this piece. Noisy timbres and textures emerg-

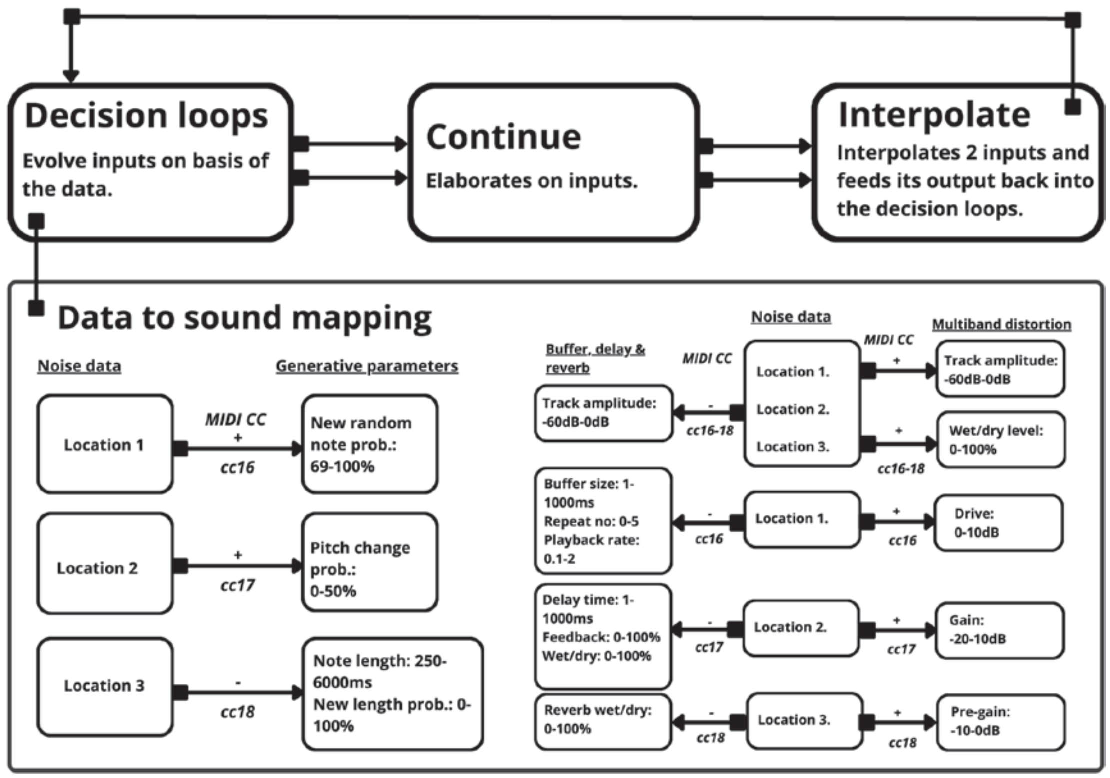

Fig. 6. Overview of Iteration 4 with data-to-sound-mapping strategies. (© Stephen Roddy)

ing from arrhythmic and eurythmic patterns of activity now recalled the city as it was pre-pandemic. Cleaner, clearer, and simpler aesthetic patterns were now characteristic of the urban quietude experienced in Dublin during the pandemic.

I created a fixed audiovisual composition in two movements. The first movement used data from March 2019, before the pandemic. The second movement used data from March 2020, the point at which the pandemic was worsening, and Dublin was preparing for its first lockdown. To address the loss of a tangible live performance element, I developed a data-driven visual component for the piece.

This involved the creation of a data-driven dot distribution map in the shape of Dublin. In this visualization, random processes applied to the radii and colors of the individual dots are constrained in their extent and directionality by the data values recorded at noise level sensors across the city. I created the visualization with a variety of technologies. I programmed the visual elements in Processing 3 and used Python, specifically the NumPy and Pandas libraries, to clean and prepare the data. I then mapped the data to Open Sound Control (OSC) messages with the pyOSC library and sent these messages back to Processing to control the visual parameters. This shift to a fixed audiovisual mode of presentation changed my role again to that of an observer and audience member, as I could now experience the piece passively without having to actively perform it.

This new audiovisual piece, *Signal to Noise Loops v4: A Quiet Year*, was performed at the 2021 New York Electroacoustic Music Festival, the 2021 Audio Mostly Conference at the University of Trento, Italy, for the sixteenth edition of Culture Night / Oíche Chultúir, and for The Video Sound Archive S3 in 2022 [36–39]. A still from the visual component of this piece is presented in Fig. 7. The sonic component of *Signal to Noise Loops v4: A Quiet Year* was installed for listening at the International Conference on Computer Music in Santiago, Chile, in July 2021, and was broadcast on October's Monthly Diatribe on Dublin Digital Radio in 2021 [40–43].

REFLECTIONS AND OBSERVATIONS

I approached the work involved in the *Signal to Noise Loops* project from a cybernetic perspective. Applying feedback-like strategies, I adapted new iterations of the system to better reach my intended goal for the next performance. Through feedforward strategies, I anticipated problems that might arise during performances and steered the development of the system to avoid them. In this way, I guided the project toward my initial goal: data-driven musical collaboration.

This initial pillar of cybernetic thought, the loop, became integral to the development of the project. It manifested itself in the first performance in the form of live phase-shifted loops of recorded audio, but quickly developed to become a decision-making structure from the second performance onward. Audiences received the first two performances positively; one prominent computer artist offered particularly memorable praise that favorably compared the sonic effect of the performance to the Visigoths marching on Rome in 410 CE.

By the third performance, my goal had morphed. I became interested in treating the data as a musical performer and the performance system as its instrument. There were hints of this forthcoming course correction from the outset. My original goal represented a partial act of surrender, in which autonomy is transferred from the artist to the system developed to realize the performance. In hindsight, there is an echo of the aleatoric approaches Cage developed in *Music of*

Fig. 7. *Signal to Noise Loops v4: A Quiet Year.* (© Stephen Roddy)

Changes [44], and the improvised nature of the musical input recalls Oliveros's embrace of improvisation as a strategy for removing herself from the musical process [45].

As the project progressed, my role increasingly shifted from that of performer to that of a supervisor who, having set up the system and the performance, would interfere only when an issue or problem arose. This reflects Stafford Beer's later conception of cybernetics as the "science of effective organization." By von Foerster's standard, the system remains reflexive, as it is a product of a human mind and contains a human-in-the-loop. All that has changed is my role as performer. However, the sense of purposeful forward motion to which the audiences of the first two iterations had reacted so positively was lost in this process; as I introduced more data into the system, the sonic result became increasingly erratic and unstable. I addressed this in the next iteration by returning to the noise data with which the project had begun.

In the fourth iteration, I focused on developing a musical system that could be played by the data alone without losing the sense of spontaneity provided by the improvised musical inputs I had provided in earlier iterations. I employed machine learning tools to elaborate and iterate upon materials provided by the generative component of the system. The aim was to retain the sense of freedom, discovery, and surprise inherent in the improvised passages.

When, in response to COVID-19, I made the project into a fixed audiovisual installation, this distinction was lost. The pandemic changed Dublin and its role in the project. Prepandemic, the city data drove musical decision-making, and this resulted in the emergence of the rich aesthetic patterns from the performance system. With COVID-19, the city fell increasingly quiet, and the complex noisy patterns that previously drove decision-making were now simple and direct. The pandemic was represented in a clear and stark manner. This was an unexpected and unforeseen behavior of a system that had been designed to deal with a vibrant and bustling European capital. I chose to highlight this behavior in the final piece, and my choices in regard to the data used, the visual component, the structure of the piece, and the mode of presentation were intended to support this.

What the system does not capture is the brief flourishing of urban wildlife that took place during the COVID-19 lockdowns, as unexpected encounters with wildlife became a defining feature of the lockdown experience in the city [46–48]. Smart city sensor networks are primarily focused on human activity and, as a result, the reclamation of public spaces by urban wildlife is not clearly registered in the data. This reminds us that a city is always more than the sum of its quantifiable human activity and recalls Mattern's argument for the critical importance of those urban intelligences that cannot be so easily quantified. In future performances beyond Iteration 4 of this project, I intend to explore ways to integrate a broader range of urban intelligences into the system while retaining the sense of aesthetic cohesion evident in the earliest and latest iterations, using qualitative data sources to augment the smart city data.

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