

Future Research Challenges in Feedback Musicianship

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ABSTRACT

Feedback Musicianship is an approach that explores the recurrent circulation of signals as a core approach to making making. Recurrent circulation of signals leads to complex emergent behaviours and multistable dynamics in musical instruments, that demand new musical approaches. The AHRC Feedback Musicianship Network ran for a year, bring together researchers and practitioners to share knowledge and craft of building and playing feedback instruments, and to discuss salient issues and questions in the field. Based on these activities, this article sets out a research agenda for future research in Feedback Musicianship.

KEYWORDS

Feedback; complexity; instruments; design; performance; composition

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1. Introduction

What is *feedback musicianship*? We can think of it as an approach to making music, that explores the recurrent circulation of signals as a core of musical agency. This circulation of signals (be they acoustic waves, continuous values in a computer, discrete information or otherwise) leads to the complex, nonlinear behaviours and emergent multistable dynamics. A musical instrument (meant in the broadest sense) played in this way has a complex response to both the external environment, and to the history of its own internal states. This type of behaviour can be hugely rewarding to engage with as a player; also it can be uncontrollable, unrepeatable, but many *feedback musicians* would say they are happy to give up conventional levels of precise control in order to play musical instruments in alternative ways. Feedback offers us new and challenging approaches to engaging with musical instruments, and new opportunities for *musicking*.

The feedback paradigm is becoming increasingly prevalent in research and artistic practice in experimental music and instrument design; we've seen flurries of experimentation resulting in unique new instruments and performance practices, and renewed focus on theory supporting feedback systems. As such, the Feedback Musicianship Network (FMN) was formed to respond to growing resurgent activity in this area. Funded by the UK Arts and Humanities Research Council, the FMN activities ran for twelve months from June 2021, encompassing online meetings and three symposia in Copenhagen, Athens and Brighton. The guiding aim of the network was to bring together

musicians, researchers, luthiers, designers, and others broadly involved in feedback musicianship, to share knowledge and artistic practice, and to discuss how the field might move forward. The activities of the network are documented on the project website¹. This article attempts to synthesise the discussions and examples of practice that took place into a research agenda, illustrating these with case studies of musical practice, and describing the challenges that the field of feedback musicianship could focus on in order to move the field forward. The research agenda is built upon the extensive, rich and varied experience of the participants who contributed to the FMN.

1.1. Historical Themes in Feedback Music

While there is clearly growing energy in the field, Feedback Musicianship has a rich history. To contextualise current research challenges, we begin with an overview of this history of the musical feedback, showing the path of research and artistic practice leading to this current era. There are several papers that already tell this story from different angles (e.g. Sanfilippo & Valle, 2013), so here we briefly introduce these stories together under a number of themes. We chose the themes to structure existing accounts, whilst acknowledging that they are loose and weave through much of the work described.

1.1.1. Spatial Feedback

Some of the earliest and most iconic uses of feedback as a musical material came from electric guitar players, beginning in the early 1950s. While the solid body electric guitar was originally designed to prevent issues with feedback (McSwain, 2002), musicians such as Guitar Slim and later The Beatles and Jimi Hendrix created feedback systems between guitar and amplifier. Within these systems, loudly amplified sound from the guitar resonated its own strings and body, and the resulting tone could be manipulated by moving the guitar in relation to the speaker cabinet, and by damping, exciting or bending the pitch of the strings. They played this feedback musically as part of their live shows and in recordings. Notably in videos of Hendrix’s performances (Henderson, 1995), we can see how feedback expanded the expressive capabilities of the guitar. The practice has evolved through generations of guitarists, from My Bloody Valentine’s mix of real and sampled feedback (McGonigal, 2007) to Laurie Anderson’s *Lou Reed Drones* installation (Venning, 2022). In the 1960s and onwards, further spatial feedback techniques began to emerge in studio and performance practice, examples including Ashley’s *The Wolfman* Saladin (2017), Reich’s *Pendulum Music* (1968) (Schwarz, 1981), Lucier’s *Bird and Person Dyning* (1975) (Saladin, 2017) and Collins’ *Pea Soup* (1976) (Collins, 1976), all of which explore relative positioning of microphones and speakers to navigate feedback systems. One can also find these techniques, opened outwards into ecosystems and interactive environments, in the works of Tudor (e.g. Rainforest (Driscoll & Rogalsky, 2004)) and Di Scipio (Di Scipio, 2003). Di Scipio discusses the role of audio feedback within the wider frame of circular causality in his work (Anderson & Scipio, 2005). van Eck (2017) offers a detailed history of spatial feedback works.

¹<https://feedback-musicianship.pubpub.org/>

1.1.2. *Electronic Feedback in Studio Practice*

Feedback techniques have been documented in early electronic music studio instruments. Mashkovich's 'device to produce sound effects' (1929) re-circulated sound through a pipe using an array of microphones and a loudspeaker (Smirnov, 2013). Shaeffer and Poullin's *Morphophone* (1953) comprised of tape mounted on a rotating disc with multiple magnetic heads, allowing creation of complex feedback paths (Teruggi, 2007) (although the working of the machine was problematic). There's little documentation though of how composers may have used feedback as a creative material with these machines. With the works of Bebe and Louis Barron in the 50s however, one can see the origins of creative approaches to feedback which still resonate today. They built circuits of electronic components; they prodded them into life, sometimes by regulating feedback, and recorded them as their sounds evolved and died. Their approach to instrument building embraced unpredictability and instability (Greenwald, 1986). This approach helped them to work within the limitations of the studio technology of the time, a theme echoed by Nicolas Collins in his keynote at the FMN meeting in Copenhagen. He talked about why feedback became a common technique in early electronic music: *'Feedback was very much a go-to working material for early electronic music in the United States if you wanted to do things live, and the reason was, there really were no affordable instruments of any other kind, plus that you know feedback is a very malleable, performable thing, unlike say buying one test oscillator, and just turning it up and down and adjusting the volume, it has a high degree of interactivity'* (Collins, 2021).

Elianne Radigue's *Feedback Works* (1969-70) are a canonical example of the emergence of using the studio as a feedback instrument (Molleson, 2017), working with tape loops and analogue synthesis. Radigue speaks eloquently about the shift in musicianship that working with feedback evokes, as a dance of precision and openness:

"It is particularly feedback – which produces immediate, purely electronic phenomena that are wild and not easily tamed – that brought me back to the very foundations of musical thought. Indeed, the very nature of these types of sounds demands another approach to listening in order to better understand or hear what they awake in us ... It's as if the sound had an autonomous life which must be respected." (p. 43 - Eckhardt interview).

These themes of agency and openness crop up again and again in feedback musicianship and will be revisited in section 3.2. Another example in this period is Roland Kayn, who took a cybernetic approach to composing electronic music, *'built on a generative process in which existing sound materials are fed back on themselves in order to create deviations from that which came before'* (Patteson, 2012). Feedback also drove the characteristic sound of dub music; King Tubby developed studio techniques in the early 70s for manipulating sound through feedback loops of delays, reverbs and filters (Burgess, 2014).

1.1.3. *Algorithmic Approaches to Feedback*

Feedback has been a consistent component in digital sound synthesis since early systems such as FM synthesisers, although it's hard to find documentation of musicians using digital feedback interactively as a creative material in these instrument. Tudor's Neural Network (1992-94) is a good example of the development from analog systems towards digital techniques. It used neuromorphic chips (analog signal path with digital configuration (Warthman, 1995)) to create dense feedback loops on a scale not previ-

ously possible with analog technologies. The unstable nature of the system meant that ‘*relatively small changes on the part of the performer would produce cataclysmic changes in the overall texture of the sound*’ (Tudor & Collins, 1994). Tudor’s instrument is an early example of how digital control could influence feedback loops and configure the degree of instability in an instrument. This theme continued in research into mapping design in the late 90s and early 2000s, a prominent example being Hunt and Kirk’s work on expressive mapping (Hunt & Kirk, 2000). While not explicitly about feedback musicianship, it laid some groundwork for today’s feedback instruments, with a focus on nonlinearity and complexity in interaction design. This is echoed in Bowers and Hellström (2000) dynamical mappings for exploration in improvised electro-acoustic music and ‘*usability at the edge of control*’. Jorda’s work on digital lutherie (Jordà, 2004) discusses *uncontrol*, which further describes how instruments change behaviour when they are pushed into non-linear modes, again, a foundational concept of feedback instruments. In the early 2000s we also see further digital feedback systems begin to emerge. For example Di Scipio used digital signal processing to configure the dynamical behaviour of his *Audible Eco-Systemic Interface* project (Di Scipio, 2003) and Eldridge explored cybernetically-inspired digital models based on feedback (such as homeostasis and neural oscillators) as control systems and generators to create interactive generative performance systems (Eldridge, 2007). Algorithmic approaches also allowed cross-modal mapping, for example, Grierson’s piece *Structure Interne* used audiovisual feedback, by mapping from colour to sound, and from sound to image (Grierson, 2005).

In summary, the shift from pure analog to digital and hybrid systems enabled a precise approach to configuring the behaviour of feedback instruments, and also expanded the scope of feedback musicianship integrating concepts and methods from cognate fields such as artificial life, and expanding into other modalities.

1.1.4. Feedback Instruments for Live Performance

Feedback musicianship has a solid but lesser-known history in very early live electronics. In what is arguably one of Britain’s earliest electronic sound performance in 1895, John Gray McKendrick’s demonstration on ‘Sound, Hearing and Speech’ at a Royal Institution Christmas lecture featured an instrument, designed by Alfred Graham, that consisted of a microphone paired with a loudspeaker horn, driven into self-oscillation to produce brass-like tones. Preceding this in 1894, Graham had patented ‘*A New or Improved Method and Means of Producing Sound*’, which described how to configure the speaker-microphone feedback system to create different tones (Wilson, 2017). Moving forward to 1960s, the score for John Cage’s *Cartridge Music* (Cage, 1960) describes a performative approach to electronics that incorporated feedback. It asks performers to build instruments from collections of small objects, using phono cartridges and contact mics as pickups. Notably, the score has an early reference to feedback in musical instrument design: ‘*all events ordinarily thought to be undesirable, such as feedback, humming, howling etc, are to be accepted in this situation*’. Following Cage’s early embracing of feedback, we can find many new instruments that incorporate feedback as creative material, within their fundamental design and function, for both sound production and interactivity. For example, Max Neuhaus experimented with extending percussion instruments using contact microphones and feedback, to obtain ‘*a complex multi-timbred system of oscillation*’ (Saladin, 2017) in *Fontana Mix: Feed* (1965), and David Behrman used feedback in *Wave Train* (1966) to extend the grand piano, placing guitar pickups near the strings, and amplifying the signals to drive the instrument into

self-resonation.

In the 1970s, more instruments began to emerge. An interesting example is Ralph Jones' *Star Networks at the Singing Point* (1978) (Jones, 2004). The performer tunes networks of electronic components with high gain feedback loops, and once tuned, lets the networks *sing* to the audience. Around this time, Nicolas Collins began building the *backwards guitars*, a precursor to the many feedback string instruments in existence today, with a feedback loop between reverse-wired electromagnetic pickups that vibrated the strings rather than sensing their motion, and piezo pickups on the body of the instrument. These instruments exemplify a performative approach to feedback musicianship, influenced by Cage and Tudor's approach to instrument design, and facilitated by the new availability of integrated circuits (Collins, 2004) that brought experimental approaches and DIY aesthetics into analogue instrument design.

While this work was happening in the US, Michel Waisvisz was working on Crackle instruments (1973 onwards) at the Studio for Electro-Instrumental Music (STEIM) in Amsterdam, culminating in the *Crackle Box*. This instrument placed the performer's body directly within an electronic feedback loop, allowing subtle movements and pressure changes to steer the complex behaviour of the sound producing circuit (Waiswitz, 2004). This physical approach to analog electronics, which incorporated exploratory use of feedback, was echoed in Ghazala's *Circuit Bending* approach (Ghazala, 2005), which encouraged experimental rewiring and reconfiguration of electronic devices to find new sounds and new modes of interaction. Echoes of these exploratory approaches to electronic instruments can be found in the practice of no-input mixing, which emerged with artists such as Toshimaru Nakamura in the mid-1990s and continues today (Chamberlain, 2018; Mudd, 2023). No-input mixing is a re-appropriation of the standard mixing desk, wired with circular signal paths to create emergent sounds that begin in the analogue noise inherent in the circuitry.

In the 2000s, we begin to see new hybrid instruments emerge, a prime example being the *Thranaphone* (Hjálmarsson, 2007). Descended from the design patterns of Collins' Backwards Guitar, it uses a resonant body with microphone and exciter to create the feedback loop, but the resonant body is a tuba, and the microphone is held in the player's mouth, the shape of their mouth guiding the feedback. Another hybrid example is Bowers' virtual/physical feedback instruments (documented in (Waters, 2007)), which created a feedback loop between a physical instrument and its physically modelled counterpart. Bowers also experimented with electronic approaches in *Ohm My God* (2007), a bowl of electronics components explored with probes, and electro-mechanical approaches in *The Victorian Synthesiser*, which comprises voice coils, tilt switches and a conductive plate. Both instruments, along with Graham's original *Victorian feedback instrument*, demonstrate the power of feedback to create complex sound and afford rich musical interactivity from seemingly basic elements.

2. Research and Musical Practice: The Current Landscape

Feedback musicianship today is building upon these historical approaches by bringing contemporary maker/fabrication technology and new digital signal processing techniques to create fresh approaches to customised and hybrid (digital/acoustic/electronic) instruments. Many of the same theoretical tools from chaos, complexity and dynamical systems continue to be explored. Innovations in deep learning are building upon these tools. The delight in and respect for the intrinsic autonomy of emergent feedback processes that Radigue and others expressed are evident in

contemporary performers’ accounts of the experience of and allure of feedback musicianship, and are revisited within contemporary frames of enactivism, new materialism and more-than-human design (see e.g. Giaccardi, Redström, and Nicenboim (2025)), to which they bring a valuable, manifest means to experiment with ethical approaches of making-with the world.

2.1. Innovations in Feedback Instrument Design

Inspired by the Thranophone (Hjálmarsson, 2007), the *Halldorophone* (Úlfarsson, 2018) was a catalyst in the current renaissance, first developed in 2008. It inspired a series of new instruments including the Feedback-Augmented Double Bass (Burstström, 2015), the Feedback Cellos (Eldridge & Kiefer, 2017), Feedback Double Bass (Liontiris, 2018), and the Feedback-Actuated Augmented Bass (FAAB) (Úlfarsson & Melbye, 2020). Descriptions of these developments and others have been summarized in a survey article, placing such instruments into a taxonomy and reflecting upon how they are characterised, designed, and played (Eldridge, Kiefer, Overholt, & Úlfarsson, 2021). The article presents a variety of self-resonating vibrotactile feedback instruments (SRIs) which are defined as those which incorporate a feedback loop between a pick-up and an embedded electro-mechanical acoustic actuator. This makes them very sensitive to physical interaction by the player while also allowing properties of the resonant materials to colour the vibrations. Twenty different SRIs are described under five categories: 1) strings and springs, 2) air and tubes, 3) membranes and surfaces, 4) assemblages, and 5) signal processing algorithms. Self-contained resonance through feedback is a core design pattern that sets SRIs apart from other resonator instruments, for example McPherson’s *Magnetic Resonator Piano* (McPherson, 2010) or the iconic feedback of Jimi Hendrix’s guitar and amplifier. SRI designers are innovating methods for combining acoustic materials with transduction techniques, new ways of processing signals (digital and analog) that pass through these hybrid interfaces, and new methods for interacting with these hybrid feedback loops.

There have also been innovations in spatial feedback instruments. Collins’ piece *Roll, Pitch, Yaw* blends glove-mounted electromagnetic pickups with a mixture of driver coils, and infrasonic/ultrasonic pitch shifting (Collins, 2022). *Hertzian Field #2* by Stelios Manousakis couples bodily interference in WiFi signals with audio feedback (Manousakis, 2016). Feedback between FM transceivers forms the basis of a work by Andreas Bergsland (Bergsland, 2023). Alberto Rizzo modulates an ultrasonic feedback loop with hand gestures, interacting with sound synthesis controlled by a neural network (Rizzo, 2022), and Lauren Hayes explores technologically-mediated site-specific sonic responses and environmental considerations in *Sounding Out Spaces* (Hayes, 2019).

The role of AI in feedback instruments is also beginning to be explored. Feedback is of course a core component in many AI systems: in autoregressive models, in the balance between generator and discriminator in generative adversarial networks, and in the relationship between agent and environment in reinforcement learning. These fundamentally iterative, adaptive processes lend themselves naturally to feedback musicianship; creating nested feedback loops across hybrid materials adds to potential for complex behaviours and rich performance experiences. The *Proto-Langspil* (Armitage, Magnusson, Shepardson, & Úlfarsson, 2022) (discussed in more detail as a case study in section 3.1) opens up string feedback to embedded machine learning processes. Kiefer and Eldridge’s *feedback feedforward* uses a simple multilayer perceptron to add

a second-order feedback loop to their shared feedback cello-analogue synth instrument (Kiefer & Eldridge, 2022). Kiefer’s *Xiasri* ((FMN, 2022), as captured in performance by (dox TV, 2022)) is a string SRI, that uses a generative audio RAVE model (Caillon & Esling, 2021) trained on the instrument’s own sound as part of the feedback loop.

Feedback continues to be a rich element of generative instruments. For example, David Dunn’s piece *A Lambent Mirror for Remote Ontographies of Nested Infinities* Dunn (2023) creates sound from complex networks of analog and digital elements. *Thresholds and Fragile States* by David Kant (2015) is an exploration of Dunn’s work, moved into digital form. The theme of generative music from complex network feedback is prominent in the work of Surges (2015) and Monteiro (2022).

In the audiovisual domain, Duff (2023) performs with analog synthesis and analog visuals, recycling signals between a modular synthesiser and a vectrex display, and Novello (2021) explores audiovisual feedback between modular synthesis and laser display.

Despite feedback being one of the oldest techniques in making electronic music, feedback approaches are not yet prevalent in mass-produced commercial instruments. Whilst enjoying success in certain niches (experimental music, film sound production), feedback instruments have yet to see wide-scale adoption. There are, however many examples of commercially available feedback instruments. For guitarists, the EBow has been a standard tool for decades, using electromagnetic feedback to sustain notes. The Moog Guitar (2013) built electromagnetic sustain into the instrument itself, but the guitar has now been discontinued. Its designer Paul Vo continues to work in electromagnetic string feedback including the *EMPick*. Feedback is available in some DAW plugins - various resonator and physical modelling plugins can be excited into self-oscillation. Some DAWs (probably sensibly) actively track and inhibit cyclic signal routing, creating barriers to experimentation with digital feedback systems. Feedback has long been a technique in analog and modular synthesis. Arturia’s Brute synthesisers makes this explicit, with the *Brute Factor*, a gain control for a feedback path from output back to input. Dave Smith’s *Morpho* has a similar feature. In the realm of vibrotactile instruments, the *PiezoThing* from Araya Instruments² packages a piezo microphone and an exciter into a battery-powered portable unit. The Halldorophone is commercially available, and instruments have been sold worldwide.

2.2. Theoretical Research

There is a growing body of academic literature that develops the theoretical basis for feedback musicking. In 2021 the Echo Journal dedicated a special issue to feedback, edited by Pultz-Melbye (Pultz-Melbye, 2022). Previous to this, Sanfilippo and Valle’s review paper (Sanfilippo & Valle, 2013) made a significant contribution towards shaping the field. Feedback musicianship has been present across many music conferences, but some events have specifically focused on the field: *The Sound of Feedback*, *The Idea of Feedback in Sound* (Impett & Wright, 2020), and the events of the Feedback Musicianship Network. Beyond these focused editions lie many important contributions, in this section we outline these, grouping by main topic, but also acknowledging that some publications fit across several topics.

Beginning with papers that look at the underlying themes of feedback musicianship, Sanfilippo and Valle’s review paper proposes a typology of musical feedback systems, and Magnusson, Kiefer, and Ulfarsson (2022) examine the core concepts in a set of

²<https://araya.se/>

interviews with feedback musicians.

Feedback musicianship’s roots in cybernetics are strongly evident in contemporary research; Hayes (2019) explores autopoiesis in feedback systems, and Eldridge et al. (2021) looks at feedback instruments through the language and terminology of Cybernetician Ross Ashby. These discussions become part of a broader theme on complexity in feedback instruments. Eldridge (2022) explores the concept of *complexity literacy*, with feedback musicianship as a means of understanding wider complex systems (revisited in section 3.7 below). The *CoFlo* system, for modulating the behaviour of feedback instruments based on complexity metrics, is documented in two papers (Kiefer, 2023; Kiefer, Overholt, & Eldridge, 2020). Surge’s PhD thesis moves into the study of complexity in generative feedback systems (Surges, 2015), and continuing in this vein, Sanfilippo’s *Order from Noise* studies the use of feedback in autonomous performance systems (Sanfilippo, 2018). Sanfilippo explores cybernetics and complex adaptive systems in detail in his PhD thesis (Sanfilippo, 2020).

Themes of agency and (un)control are central in feedback systems research and draw on a range of related theories. Although not explicitly addressing feedback instruments, De Campo (2014) explores the concept of meta-control of complex instruments. Davis (2019) addresses intentionality with the *Feral Cello*, and Melbye (2021) discusses mastery and agency from experiences with the *FAAB*. Similar ideas are shared within the framing of interaction design in Mudd et al’s (Mudd, Holland, & Mulholland, 2019) paper on non-linear dynamics in musical systems and Ulfarsson et al’s (Úlfarsson, Magnusson, & Moraitis, 2023) discussion of *ergodynamics* in the halldorophone.

2.3. Musical Practice

While artists far and wide continue to make use of feedback in their music, this section will highlight just some of the current examples of those actively using feedback as a key principle in their practice. Hildur Guðnadóttir’s music made with the halldorophone has captured headlines for her Oscar winning soundtrack to the *Joker* (2019), and her scores for the Emmy-winning HBO miniseries *Chernobyl*. The wide variety of forms found in feedback music are also examined in Cathy van Eck’s book (van Eck, 2017), while the 2002 edition of *Resonance* magazine explored feedback from the perspectives of musical practitioners (Resonance, 2002). Adam Pultz-Melbye and several others have advanced the musical practice of feedback with the double bass (Burström, 2015; Lontiris, 2018; Melbye, 2021; Stewart, 2021), while the authors have explored smaller violin-family instruments (cello and violin).

Feedback ensembles, such as the Brain Dead Ensemble (Kiefer, 2019) and the experimental group named simply the Feedback Ensemble (Bordreuil, 2021) embody the transformative elements of feedback during live performance with experimental sounds and techniques. These ensembles push the boundaries of traditional music, embracing feedback to create a viscerally immersive sonic experience. The Brain Dead Ensemble acoustically network multiple feedback instruments and a live coded, multichannel, microtonal system to create an extended shared interface for multiple players which further distributes agency Lontiris (2018). Spontaneous audience comments suggest that this extends to the room itself, bringing the audience within the experience: ‘*You soon didn’t feel like you were in the room listening to the music but were inside the music, with the room not reappearing till the end*’ (anon audience member, The Green Door Store, Brighton, 16th Sept 2018). Meanwhile, the Feedback Ensemble explores the depths of sonic elements yet to be uncovered with traditional acoustic instruments

and amplifiers, weaving together elements of jazz, free improvisation, and experimental soundscapes. The performances of these ensembles invite listeners to embrace the unpredictable and embark on journeys of sonic discovery, opening up new avenues of artistic expression.

While not explicitly linked to feedback in music, it has been discovered that “Expectancy violations (e.g., harmonic, rhythmic, and/or melodic violations) are strongly correlated to the onset of musical frisson, such that some level of violated expectation may be a prerequisite.” (Harrison & Loui, 2014) However, the emotional power of such violated expectations is interesting to consider, as it is well known that feedback instruments are prone towards unexpected behaviours. The authors all performed in a new feedback ensemble, the Curious Feet Bags (Kiefer, 2022) at the final concert of the Feedback Musicianship Network in 2022, and informal comments and reactions seemed to indicate this expectation violation stimulated some audience members.

In the tradition of Steve Reich’s ‘Pendulum Music (For Microphones, Amplifiers Speakers and Performers)’, Virgile Abele has created innovative sonic pendulums (Abela, 2020), and Viola Yip created a related lazy-susan (circular platform) based feedback (Yip, 2018). Such instruments are part of a broad variety of approaches, including for example Blandhoel’s Feedbackers, Marino’s feedback cymbals, Nederberg’s gestural feedback instruments, Cybulski’s Feedback Synth and many more. Valuable reflections on artistic practice, can be found in Bower’s account of a room feedback instrument (Bowers, 2023) and Ham’s PhD thesis Ham (2024)

Gianluca Elia investigates previously unexplorable performance techniques with no-input mixing, via the design of a novel digitally-controllable analog no-input mixer (Elia & Overholt, 2024). His instrument enables hybrid approaches that aim to preserve the raw, co-creative experience of traditional no-input mixers while introducing new possibilities through digital techniques (saving and recalling parameter states, interpolations, and mappings), in addition to the incorporation of machine listening and machine learning techniques. Elia’s integration of algorithmic strategies into the no-input performance paradigm parallels the use of signal modulation in the feedback loop more generally. This integration of programmable algorithms into analogue and acoustic instruments, provides fresh opportunity for human negotiations of feedback systems. Practice-based research investigating how these digital enhancements can transform musical performance looks to expand models of interaction potentially fostering novel artistic languages and practices.

3. Research Challenges

The principle aim of the Feedback Musicianship Network was to cohere the community in order to generate a research agenda. Key research challenges were identified through an iterative participatory approach. Themes arising through discussions, documentation of the network activities³ and a literature review were synthesised to generate a set of proposed challenges. These were subsequently refined through discussion on the community mailing list⁴. Key items of documentation included:

- (1) Videos from five concerts, covering many different instruments and performers
- (2) Videos of three keynote talks and ensuing discussions, from Nicolas Collins, Kristina Andersen and Cathy van Eck.

³<https://feedback-musicianship.pubpub.org/>

⁴(as documented in the mailing list archives⁵)

- (3) Photos of mind maps from two *World Café* (Fouché & Light, 2011) exercises from groups in Copenhagen and Brighton.
- (4) Notes from artist presentations in Athens and Brighton.
- (5) Video documentation from the ‘*Feedback Instrument in a Day*’ making session in Copenhagen

Through this process we arrived at a number of challenges that are grouped under the following themes: Instrument Design, Agency and Embodiment, Analysis and Measurement, Musicking, Composition Techniques, Pedagogy, Diffusion and Adoption, Beyond Musicianship and Research Methods. A description of each is further illustrated by a case study interview and followed by a list of challenges.

3.1. Instrument Design

The challenges associated with designing Feedback Instrument inevitably inherit from the well-documented explorations of the *design space* for musical instruments in general, Digital Musical Instruments - DMIs, and New Interfaces for Musical Expression - NIMEs in particular. Many existing frameworks for evaluating musical interfaces can be adopted e.g. (Overholt, 2009). However, the unique characteristics of complexity and multistability in feedback instruments require extra considerations, when designing expressive instruments in this domain.

3.1.1. Case Study: The Proto-Langspil

As a case study, we asked the creators of the proto-langspil (Armitage et al., 2022) for their insights into how they designed and built the instrument for ongoing research into feedback musicianship and machine learning. The overall question we had was: how were your design choices guided by having feedback as part of the instrument? The answers consider the physical form, the choice of hardware, extensions in software, and approaches to design combining a triangulation of 1) intuition (open-ended), 2) tinkering, and 3) measuring.

The proto-langspil serves as an innovative example of instrument design that incorporates feedback as a fundamental element. The design choices were guided by the aim to create an instrument that not only responded to player input but also exhibited a degree of agency and autonomy, enhancing the interaction between musician and instrument.

The physical form and aesthetic of the proto-langspil were intentionally designed with an unfinished, prototypical look, making it conceptually, musically, and technically malleable. This design choice encouraged openness, potential for augmentation, and customization. Its physical structure includes features such as moveable frets and multiple strings, allowing for a variety of playing styles and interactions. The design also incorporated a hollow body with electric pickups, integrating both acoustic and electronic elements to facilitate feedback.

In terms of transducers, the proto-langspil uses a 20W tactile exciter, a 50W class D amplifier, and Cycfi Nu⁶ pickups. These elements are critical for generating and controlling feedback within the instrument. A single-board computer (Bela Mini) with an audio expander is used for digital signal processing, allowing real-time manipulation of sound, and enhancing the feedback loop between the player and the instrument. Additional hardware includes ferromagnetic guitar strings, which interact with the

⁶<https://www.cycfi.com/projects/nu-series/>

pickups and transducer to create a responsive feedback system. The instrument also has slots for mounting external modules, inviting further experimentation with the feedback mechanism.

Software extensions play a crucial role in the proto-langspil's feedback capabilities. The software running on the Bela Mini manages feedback and signal processing, allowing for various levels of feedback intensity, which can be controlled by, for example, foot pedals. This setup enables musicians to dynamically adjust the feedback during performances. Customizable software elements encourage users to experiment with different configurations to explore new sonic possibilities. For example, one participant in a study reprogrammed the proto-langspil using SuperCollider, a platform for audio synthesis and algorithmic composition.

The interaction and agency of the proto-langspil were central to its design. The instrument was intended to provoke rethinking of its potential by appearing both familiar and experimental. It was not just a tool but a collaborator, described by one user as having its own agency, responding to and sometimes leading the musical interaction. The instrument's capacity for autonomous feedback was intended to blur the lines between player and instrument. This was evident in experiences where players describe that the proto-langspil seemed to follow their actions before independently generating new sounds.

The project also explored the socio-technical implications of embedding AI and machine learning in musical instruments. By making simple changes to the software, researchers aimed to study how people attribute agency to objects and engage with the concept of *intelligent* instruments. This approach aligns with the team's research goals of examining anthropomorphisation of technical objects and understanding the performer's perspective on intelligence and agency in instruments.

In summary, the proto-langspil's design was fundamentally influenced by the goal of integrating feedback as a core feature. The combination of innovative hardware, adaptable software, and a flexible physical form created an instrument that not only responded to but also interacted with musicians, fostering unique collaborative musical experiences.

The proto-langspil is illustrative of contemporary hybrid instrument design patterns in feedback musicianship. Within this framework, there are significant research challenges, which arose repeatedly in FMN discussions. A core issue is in how to create and manage interactions between acoustic, analogue and digital systems. The choice, placement and mounting of pickups, actuators and sensors can have a significant bearing on the behaviour of an instrument, and the effects of small changes may be unpredictable. Signal processing is fundamental to most feedback instruments, and in hybrid instruments, the processes are embodied in the physical feel and behaviour. Just as with transducers, small changes in signal processing can have strong effects on the overall dynamics of the instrument.

With such sensitivity to small changes, feedback instrument design can sometimes seem like a delicate feat of balance, but perhaps there are opportunities to take a more systematic approach? Designing these instruments is essentially designing the emergent behaviour of complex systems. This may seem like an oxymoron, but there are many ways in which we can measure and gain insights into the behaviour of complex systems; this challenge has been explored in other domains such as Artificial Life Art (see for example (Eldridge, Dorin, & McCormack, 2008)). Mathematical tools for measuring complexity and describing higher level features of dynamical systems will also be useful here. These processes can be built into the mappings of the instrument, so that instruments can adaptively self-regulate. Beyond specific complex and dynamical

systems tools, machine learning offers methods and models that could support analysis and modulation of feedback system dynamics. These tools could potentially support designers in making informed choices about the configuration of materials, transducers and signal processing.

3.1.2. Challenges

- Gain deeper insight into the musical potential of hybrid instrument (physical/analogue/digital) including acoustic materials, transducers (pickups, sensors, actuators), signal processing (analog/digital) and their interactions.
- Design and evaluate software (frameworks, algorithms, signal processing) for measuring and managing complexity, nonlinear dynamics, and emergence in hybrid feedback systems.
- Consider how existing NIME design and evaluation frameworks can be adapted to support feedback musicianship
- Learn from related fields, such as Artificial Life, that have developed techniques for complex systems design

3.2. Agency and Embodiment

Interacting with feedback systems entails questions of (inter)agency and embodiment. The well-known axiom in which instruments can be considered as extensions of a performer’s body is both challenged and extended in the field of feedback musicianship. Here we aim at gathering theoretical perspectives to support understanding of how systems with a degree of autonomy challenge the relationship between musician and instrument. We begin by looking at a refinement of the concept of musical embodiment in which the musical performance situation is considered from an ecological perspective (e.g. performer, instrument, score, audience, room...)(Rodger, Stapleton, Van Walstijn, Ortiz, & Pardue, 2020) as well as a communication domain, with the instrument as mediator of a mutual interaction(Nijs, Lesaffre, & Leman, 2013).

3.2.1. Case Study: Paul Stapleton

We talked with Paul Stapleton regarding his own perspectives on agency and embodiment in feedback musicianship. Stapleton shared that he hit a wall playing traditional instruments (violin, guitar), explaining that ‘*I was in too much control, I was falling into very predictable patterns, and got a bit stuck in my playing*’. He then started building instruments that resisted mastery in the traditional sense, by having unstable and unpredictable behaviors. Some of them were sound sculptures, built out of metal with strings, including various mechanisms that created instabilities. By resisting some of the player’s intentions, such instruments require musicians to learn to play in different ways. Playing methods can be compared with sailing a ship, which has momentum and external influences alongside human technique. In his next phase of feedback instrument development, Stapleton incorporated the digital and/or electronic domains as well - not just the acoustic or mechanical elements. His deliberate use of feedback built upon things like no-input mixers, modified turntables, transducers and microphones, and speakers / tactile sound transducers to create pathways through acoustic materials, or through virtual acoustic materials that were tuned in specific ways in order to create inter- or distributed agency.

In practical terms, Stapleton embraced feedback as a means to distribute agency

across a variety of actors within a musical ecosystem. Seeking to think through this experience led him to enactivism, via systems theory and autopoiesis (Varela, Thompson, & Rosch, 2017). The term autopoiesis was coined by philosophers of biology Humberto Maturana and Francisco Varela to describe systems which function as a self-defined unity - where the functional operation, structure and boundary are produced by the system itself. They are operationally closed, self-defining and self-perpetuating; scaled up, this type of autonomy gives agency which is both located in the autonomous systems that are interacting with each other, and the interaction itself. This approach provides further elaboration beyond simple distributed agency. For Stapleton, the motivation is *‘to understand where my own responsibilities, possibilities and importance lies, where and how I can enter into relationships with others (not just humans, but instruments, systems) based upon feedback or other types of agents (AI, chaotic) to produce music through interactions between various actors’*.

During the interview, deeper questions regarding (inter)agency and embodiment arose, and Stapleton’s approach to practice-based research uncovers some of the allure of feedback musicianship to many. For example, he talks of his feeling that *‘slight nuances and pressure movements, damping resonances - those are things that require practice, and a shift towards an embodied way of knowing where your hands and ears, and the rest of your body, couple with the system so that we can develop skill over time.’* As Stapleton notes, mastery and therefore instruction takes a different form than that associated with more traditional instrumental practice: *‘I don’t wish to directly impart exact techniques, but I can give strategies that others can then adapt and use and develop in their own music.’* In summary, Stapleton thinks that *‘feedback is a necessary quality of any living system, fundamentally movement and the propagation of movement, and once things reach equilibrium, it’s death.’* This means that embodied approaches to interacting with feedback instruments are crucial, letting the system’s agencies react to our own agency as performer. When feedback is so defining that key instrumental responses and behaviours are emergent - having some degree of dynamical autonomy - it is important to work with that particular instrument’s identity/personality/character; this is invariably a challenge unique to the idiosyncrasies of particular instruments - and part of the joy of the field.

3.2.2. Challenges

- Understand how specific design decisions inform different forms of agency in feedback instruments and how these relate to performance and composition challenges.
- Investigate the ways in which player-instrument interactions differ from traditional paradigms. What are the implications for design and player experience?
- Consider how theories of agency and autonomy from wider fields (cognitive science, robotics, philosophy, new materialism, ecofeminism etc.) can provide a deeper understanding of the relationship between player and instrument, and of feedback instrument behaviours.

3.3. Analysis and Measurement

Feedback instruments have expanded the repertoire of designs based on the use of recurrent signals, and broadened the possibilities of expression and performance. However, the complexity and nonlinear dynamics of feedback systems can seem to thwart methodical approaches to establishing precise descriptions of their behaviours. It is im-

portant and interesting to analyze the couplings between a system’s elements, and how they contribute to the overall system behaviour. Some may consider best approaches to be purely experimental and musical practice-based, however measurements can examine specific resonances in materials and systems that are possible to explore in feedback performances, further informing artistic processes with feedback instruments.

3.3.1. Case Study: Øyvind Brandtsegg

While there are many different approaches that can be applied, Øyvind Brandtsegg’s method of making pitch maps for vibrotactile feedback instruments is perhaps one of the most considered examples of a methodology (Brandtsegg, 2022) for measurement and analysis. His open source feedback-plate-analyzer⁷ software allows instrument developers to record, analyze, and measure energy levels at various points on the surface of an instrument. His scientific and artistic motivation for developing it stemmed from an issue common to all feedback instruments: the challenge of intentionally playing specific pitches.

We talked with Brandtsegg about his instrument, the Piezo-Finger-Feedback-Plate⁸ and how he analyzes its behaviours, given the many different vibration modes it can enter. While his software allows some elements to be modeled numerically, there are additional factors which also have clear influences on the resonances of the feedback loop, such as sound travelling through the performer’s finger up to the piezo-ring pickup, closing the loop in his design. Other factors that are well known, relate to the frequency and phase responses of all the combined components in a feedback loop. Taken individually, such constructive and destructive interference patterns are quite simple, but the interactions between them become complex.

The result of building such a system (instrument) provides a performer interesting balances between instability and controllability, and Brandtsegg notes that *‘the influence of phase plays a significant role in the increased complexity.’* He also comments that even after developing a full pitch map with his software, just explorative rehearsing on the instrument would probably have achieved similar results, and that *‘some positions on the plate could have maybe five different pitches depending on how hard you press.’* So, getting to the essence of the instrument requires full body/mind concentration. One of the great aspects of this particular instrument’s conception, is to literally include a portion of the body (the finger) as vibratory material(s) within the loop.

Brandtsegg notes that *‘I didn’t expect the pitch maps to be reproducible - it was more like a general idea of where you could find what kind of range, or where it is more complex/simple.’* This means that such instruments will always require sensitive adaptivity when playing, as compared to the well-trodden path of mastery with traditional instruments. This fascinating form of interaction, engaging with dynamic and undulating systems does of course come with a caveat; that which Brandtsegg describes by saying *‘I can control musical phrases, but I wouldn’t say traditional melodies - you can have an intention and go there, as long as you go with the flow.’*

3.3.2. Challenges

- Adapt, innovate and evaluate analysis methods that are amenable to observing and influencing feedback systems. Where can we adapt analysis techniques

⁷<https://github.com/Oeyvind/feedback-plate-analyzer>

⁸<https://oeyvind.github.io/vibrotactile/2020/10/16/demovideo.html>

from engineering, acoustics, dynamical systems or complexity sciences? And what changes do we need to make to observe musical feedback systems?

- Explore how analysis methods can lead to visualisations of feedback system behaviour, that might deepen musical understanding.

3.4. Musicking

For several hundred years Western music has been based on composition and performance. [...] We have been so concerned with language that we have forgotten how sound flows through space and occupies it. (Lucier, 1995)

Feedback musicianship presents ongoing challenges as our instruments, players and audiences inspire new cultural practices. We take Christopher Small’s term *Musicking* as a useful term for describing feedback musicianship. *Musicking* describes musical practice as encompassing the broader activities around music, and highlights the relationships within this ecosystem; similarly the unique challenges of feedback musicianship demands that the player understand how the instrument is situated within a complex system of people, environments, technologies and so on.

We can ask, how might Feedback Musicking differ from other Musicking? A key difference could be around the way feedback necessitates reactive as well as proactive approaches; the implications are that our experience is highly contextual, and not always directly transferrable, giving us challenges in how we share and discuss experience. Perhaps we need to focus on fundamental meta-skills that break ties to context, in which case what are these meta-skills? Our interview with Cathy van Eck sheds some light on this question.

3.4.1. Case Study: Cathy van Eck

Cathy van Eck is a composer, sound artist, performer and author of the book *Between air and electricity – Microphones and loudspeakers as musical instruments* (van Eck, 2017). Musical feedback features prominently in her works. We interviewed van Eck, discussing her approach to three of her pieces: Wings, Chairs and Music Stands. All of these pieces involve careful configuration and movements of objects, microphones and speakers, varying from solo pieces to group performance with a choreographed score.

We began by discussing van Eck’s approach to working with feedback; how one can influence (rather than control) a system, and also how much can you ‘not influence’ and give the system space to evolve. She felt ‘tuning’ to be one of the most important skills when working with feedback ‘*it’s really about tuning and getting an ear for the responsiveness of the feedback*’. This skill is particularly important given the variance and unpredictability of feedback, due to, for example dependence on resonance of a particular room, and the uneven landscape of influence ‘*sometimes a centimeter can change much more, and then sometimes it’s like I can move quite a lot or change quite a lot, and I feel like nothing is changing, nothing is changing because it’s so strong on one frequency*’. Part of the tuning skill is to be able to destabilise a system if it’s unresponsive, and guide it to a more reactive state. Tuning is also ‘*about changing the setup and then listening to what is the result ... with feedback, it sometimes really needs two or three seconds to stabilize ... it’s about listening when you have to change; I have this feedback, so now I stay a bit longer because this is an interesting sound.*’. When asked whether decisions to change are made in the moment, van Eck replied that ‘*They’re kind of informed by what I’ve done before, informed by my knowledge of the set up ... I feel I can’t say this pitch needs to be higher, but I can say ... that*

feedback sound should change now.'. Van Eck felt tuning skills could be improved by *'doing it very often and listening to it'* but also that *'it is difficult to practice because it's difficult to engineer the situations in the first place to be able to react to them.'*

Van Eck's comments emphasise the value of tuning feedback systems as fundamental skill in feedback musicianship, and also paint the complex dualities within this skill, in being reactive but also requiring knowledge of the system, and of needing regular practice but also being difficult to practice. Such tuning also involves being able to pull the system in opposing directions, to influence a system but also let it evolve on its own, to stabilize, but also to deliberately destabilize to encourage more variety.

Another central question in Feedback Musicking is why we seem to enjoy the experience of engaging with feedback instruments? Saladin (Saladin, 2017) discusses how *'In their writings and interviews, both Lucier and Neuhaus emphasised the euphoria experienced by the loss of control triggered by feedback, which is highly unstable and unpredictable'*. We also interviewed musician Annelie Nederberg who said *'it's something with feedback. You know that you're just drawn to it and you can't stop to just go into it and play. And then all of a sudden, three hours pass ... oh, I was supposed to get caught up ... You get so enchanted in the way that it's .. what is this? ... it's sort of an almost spiritual dimension, but it's like something here that I don't understand that I need to find out what this is?'*. One way to understand why musicians experience a particular joy in playing feedback instruments may lie in accounts of the aesthetics of unpredictability. Friston and Friston (2013) offer an account of music perception based on the free-energy principle. They propose that *'music supports the prediction of the unpredictable and that this prediction fulfils a fundamental imperative that we are all compelled to pursue'*. Perhaps feedback musicking, offering a deeply embodied engagement with unpredictability in music, amplifies this imperative? Another approach might follow Nederberg's spiritual dimension, Radigue's respect for autonomy, Stapleton's allure and Lucier and Neuhaus euphoria in loss of control: perhaps after millennia of human dominion we are growing tired of human supremacy and mastery. Feedback instruments offer a space to explore approaches to co-creation that decentre human will and connect us in refreshing ways to wider agencies.

3.4.2. Challenges

- Develop new performance practices around the unique qualities of feedback instruments. How can these be shared?
- What are the unique challenges of Feedback Musicking? What skills are transferable (listening skills and tuning/calibration/configuration)? Which are unique?
- Explore the reasons behind the compelling nature of feedback music, with potential answers offered in accounts of predictive perception and more-than-human worlds.

3.5. Composition Techniques

The unpredictable nature of feedback instruments means that free, or semi-structured improvisation⁹ is common in performance. Composing for feedback instruments presents unique challenges. Notation may require descriptions of techniques rather than traditional notes; as with any adventurous musical endeavors, interpretation will

⁹examples: <https://odysee.com/@dkdox.tv:6/DK22003:5> https://youtu.be/71jPJDSJB_I and <https://open.spotify.com/album/2zk0LhlzazIgmX0KnId4WA>

vary across performers and performances. Still, composition presents possibilities for something else to be imagined, mapping out the territories of each instrument for the expression of concepts unattainable via pure or semi-structured improvisations.

3.5.1. Case Study: Lars Kynde and the Curious Feetbags

As part of the research in the one-year Feedback Musicianship Network project, a set of compositions was commissioned by the authors. Together with the chosen composer, Lars Kynde¹⁰, an ensemble of feedback instruments and performers was formed from those involved in the network. These ended up including two feedback cellos, two feedback acoustic basses, a feedback violin, and two electronic/software derived tabletop feedback instruments. More complete descriptions of these instruments, and Lars' resulting complete score 'Feedback Studies', incorporating four separate works for the ensemble, can be found online¹¹.

Throughout the process, the authors worked with the composer, lending him some of the feedback instruments and helping transform his personal cello into a feedback cello in order to engage with some of the instruments in the ensemble by learning how they work. This assisted in understanding the different possibilities they offered, letting the composition be shaped by the instruments to some degree. Following the premiere of the works, a semi-structured interview with Lars was carried out, examining both his compositional approach and the final results of this method of practice-based research.

Composers tend to have many different approaches, some more conceptually-driven than others; in the interview, Lars offered that he commonly *'enjoys an intimate relation with instruments, letting the instruments determine what the composition will become'*, but that for this particular commission he found the intricacies of the various instruments overly time-consuming and unpredictable, so he revealed that *'instead of knowing intimately how all the instruments work, I took the other approach to try to imagine a sound or a concept or a way of playing / interacting between the musicians.'*

When asked if he saw any common elements or properties across the seven feedback instruments in the ensemble, Lars felt that besides basic feedback always being possible, the instruments were very different carrying each their own sonic 'personality'. He mentioned specifically Adam Pultz-Melbye's FAAB (Feedback-Actuated Augmented Bass Melbye (2021)), as an example of an instrument that has clearly been developed with a distinct personality. Speaking about Adam, Lars notes that it is clear he has built up his own universe of sounds which he likes, while avoiding unwanted feedback resonances via hand-crafted signal processing algorithms: *'I got the impression that algorithm almost plays the instrument by itself, and since Adam has worked a lot on that algorithm a lot of his personality is built into it. He even has a fixed tuning of the strings that goes together with it and theory regarding choices.'*

Lars continued to use Adam's FAAB as an example, stating that he feels it is quite controllable in some ways, but not necessarily in the ways he as a composer desired. This is due to the aesthetic choices made by the instrument designer and embedded in the algorithms, which give the composer a predefined musical language as a set frame to work within. As each instrument presented a different set of aesthetic choices, Lars found it a challenge to find a coherent expression across the instruments as an ensemble. When asked how he felt the unpredictability / un-controllability of feedback instruments affected his compositional approach, Lars replied that he tried to avoid fixed pitches due to the musician's statements that this could be difficult. He said

¹⁰<https://larskynde.dk/>

¹¹<https://assets.pubpub.org/wn4v7ht/41655702928837.pdf>

Bulldozer

Lars Kynde

Figure 1. An extract from notation for Bulldozer by Lars Kynde, a composition for feedback ensemble: <https://open.spotify.com/track/4uoanPfYDOHtiM8RJUuQ5j>

“I think what we need is a language to speak about those aspects that are in fact predictable.” He also said that he tried to notate the musical ideas in various different ways, and viewed actual written notes (which he did incorporate into the works) more as indicators of specific actions rather than specific pitches. He still found traditional notation useful for rhythmic elements, and stated the following regarding flexibility of interpretation: *‘I found the most fruitful method of collaborating with the musicians to be a combination of scoring, aural instructions and improvisation, where musicians use the score to understand the idea, but then put the notes a little bit aside and perform the basic idea, rather than note for note what the composer has written.’*

Lars also mentioned an idea for future notation techniques that may be useful for feedback musicians, incorporating multiple levels of notation specificity for the same work. In Lars’ own words, this would mean *‘writing the notes at different levels, where one is the most fundamental idea - almost like an improvisation score - and the next layer incorporates an example of how the composer wants it to be carried out, and a third layer serves as documentation of the performed interpretation’*. Lars explains that sometimes it can be difficult for performers to relate to a pure improvisation score, because they want an example of how it can be done, yet giving an example means that some people might find it too specific - and then they can go back to the first level and see the basic idea. Again examining the problem of specific pitches with feedback instruments, Lars described one of the works he composed, Passacaglia: *‘It has to do with pitches, experimenting with how these instruments can produce consonance and dissonance - so it’s playing with that classical concept, but I didn’t dare to write specific pitches. Instead the score asks the musicians to choose and write down a sequence of tones following an overall criterion for finding suitable pitches. Because I thought if the*

musicians prior to the concert bring their specific instruments to the specific concert venue, the tones they choose there may be reproducible during the concert later at the same location'

Lars feels that it can be useful to think in terms of musical gestures for feedback instruments, for example sliding up followed by sliding down. This is something free-form enough that all feedback instruments should be able to play their own version of it, and compositionally it can be chosen to fix certain rates for performers or ensembles to execute such gestures at various points within the piece. Another compositional strategy Lars chose to use was flexible instrumentation, where different lines in the score could be chosen to be played by different instruments. In some cases, however, instruments were excluded from certain score lines due to that instrument's capabilities. For example, when a line in the score calls for holding a long tone *piannissimo*, with some of the instruments in the ensemble this is impossible. So, some elements in the score for the piece *Bulldozer 1* were thought of as being played on specific instruments (mainly regarding dynamics, percussive elements), even though Lars chose not to label each line - instead he preferred to use some of the rehearsal time to go through a process of finding out what sounds good on each instrument.

The goal of commissioning Lars to create these works during the FMN project was to gain first-hand experience with the process, exploring different composition techniques for feedback instruments. The results showed that some elements of the compositions - while the music itself was unique - were produced via well-known methods. For example, many composers produce instruction-based scores when working with experimental instruments, especially those involving generative or unstable / unpredictable manners of playing. Instruction-based scores are naturally only a portion of the experimental techniques used by avant-garde composers today, with graphical extended notations, and even animated scores becoming more and more common. These alternative notation methods certainly have an impact on the performance and interpretation of the composer's intentions, given human perception and traits that will influence the planning behaviours of musicians engaging with non-traditional scores (Sullivan & Cantwell, 1999).

3.5.2. Challenges

- Analyze various compositional techniques used specifically for feedback instrument ensembles, identifying successful approaches and potential areas for innovation.
- Investigate the challenges performers face when interpreting and executing scores for feedback instruments (given technology's influence shaping the sonic characteristics and playability of feedback instruments) with an emphasis on understanding performance practices.
- Examine the interplay between improvisation and structured composition in the context of feedback instruments, identifying strategies that maximize creative potential.
- Investigate the dynamics between composers and performers in feedback instrument ensembles, focusing on how collaborative processes influence compositional outcomes.
- Develop and evaluate new notation systems that effectively communicate performance techniques for feedback instruments, considering the semi-controlled and improvisatory nature of these instruments.

3.6. Pedagogy, Diffusion and Adoption

Given the idiosyncratic nature of most feedback instruments, it's clear that there are challenges in how transferable skills in feedback musicianship are shared and taught. The interviews in this paper have identified many feedback meta-skills that are likely applicable to most instruments, but also pedagogical challenges are tied in with diffusion and adoption of instruments; with very few people playing similar instruments, how can we share our musical practices? To support pedagogy, it's useful to consider how feedback instruments could be more widely adopted. One of the most iconic feedback instruments is Halldor Úlfarsson's *halldorophone*. The halldorophone, having evolved over the past two decades, is now produced commercially, and has a growing community of players around the world. We interviewed Úlfarsson, discussing his approach to promoting adoption of the instrument.

3.6.1. Case Study: The halldorophone

The early days of the halldorophone highlighted these challenges in asking people to invest in the instrument, highlighting the link between pedagogy and adoption: *'I used to say it has no masters, it has no repertoire, so there's always ultimately a huge risk for anybody to engage it. That's no longer true. Right so now it has performers who are professionals who are doing quite well ... people who have put their name to it, have a career, who are visible, and are somehow communicating: this is how I make music.'* The common thread in Úlfarsson's approach has been sharing halldorophones with musicians and institutions (*'it's people who give this thing its attention and their attention becomes contagious'*) and finding musicians who are willing to experiment with the instrument, as a mutually beneficial process towards the development of the instrument (*'I leave it with musicians who can do something with it... they seem to be having a pleasant time, and then they make music, which I get to see as a kind of combined fruit of our labors, which is really enjoyable.'*). This has been an emergent process (*'I was flying blind, and still am to some extent ... when I've met all these engineers, musicians, technologists, academics ... I've just been kind of tiptoeing behind the people who I presented this project to, and who become interested, and their intuitions often lead me to the next thing.'*), and often with events taking on a life of their own (*'the trump card of Hildur Guðnadóttir's success is something that I feel like I did not have a lot of control over, I mean, of course it was, you know we gravitated towards collaborating for the reasons that we had overlapping interests, and we had the conversation that somehow was natural, but her success really created opportunities for this project that I have not been able to create'*). As an example of sharing with institutions, Úlfarsson discussed how he loaned an instrument to EMS in Stockholm for two years. This was mutually beneficial, the institution were overwhelmed by the interest. They said it drew a whole new user group, many of whom would probably not have come for a residency with them otherwise. Based on this success, the residencies resulted in new musical releases and new players adopting the instrument.

A broader challenge with adoption has been in engagement with the more traditional classical world, from which Úlfarsson considers the instrument to be a descendent: *'it's impossible to talk about musical instruments as objects, because they are in symbiosis with the culture surrounding them. So, with the cultural entity of the halldorophone at the moment, it is in conversation with the concept of classical music cello playing. So that's the framing that I chose to engage with, because that's where what I found this kind of really dense culture around it.'* However, engagement with the classical world

has presented challenges: *‘I realized that for a broker of repute to put their name next to a halldorophone would probably not be a good move for them in a world that is all about tradition, just along these lines of you know what makes for a good cello, what makes for a good violin? What is the level of quality and providence for an instrument that can actually be in the hands of a world-class soloist? All of these narratives feel that they would be polluted by the fact if a broker would take a chance on something like a halldorophone. How do you present power in the scene which you know it’s really ingrained? It’s ingrained in the structures of the symphony orchestras, in the repertoire of the music that these people are, you know, amazing at performing ... it would be really amazing if the halldorophone gets to get into that, but it looks impenetrable .’*

We concluded the interview discussing the general challenges of adoption: *‘I would say the challenge has been to convince players, many of whom are very open-minded players, composers. If you find those allies, and they actually give their attention to this thing, then that overcomes the kind of resistance from players who are maybe not as open-minded [or] willing to experiment.’*, *‘Time is also a factor. If you are proposing, and of course, the instrument has to be somehow ready enough that it is worth spending time with, but once it has that, you have your allies, give them time, because time with an instrument will get you emotionally involved. It will translate into understanding, which ultimately will translate into music, which is what this whole thing is about. ... if producing knowledge is the thing, and we run user studies, and that has to work out practically and be efficient, and then you have these really short sessions. But, leaving a halldorophone with somebody for a year, and not even talking to that person, translates into something that you know will be an artwork, ... will be opinions from that person, really well-formed opinions. Now that they’ve gotten to know this thing and you know they will have showed it to their friends, and it will make that instrument more real to more people.* These are all challenges specific to the halldorophone, however they can also be seen as evident truths for the adoption of any new instrument within existing musical cultures.

3.6.2. Challenges

- Engage with existing cultural institutions to support adoption of research and musical practice in feedback music.
- Study the diffusion of feedback instruments and challenges to their adoption.
- Develop a better understanding of what it would take to create a curriculum for feedback instrument pedagogy.

3.7. *Beyond Musicianship: Bolstering Complexity Literacy and More-than-human values*

So far we have focused on how ideas and methods from other disciplines and domains can be drawn into the Feedback Musicking project. Activities and discussions during the network and beyond also highlighted the value of Feedback Musicking as generative space for knowing and being that can in turn feed back to help us deal with the world beyond musicking. We suggest that Feedback Musicking creates a valuable epistemic tool Magnusson (2009) as well a what we might call an ontological playground - a space to explore alternative modes of being in the and with the world.

3.7.1. Case study: Till Bovermann and half-closed loop

For a particular take on this perspective we interviewed instrument maker researcher, Dr. Till Bovermann. Trained initially in computing, alongside classical music, Bovermann explained that understanding the world through data was foundational to his career. Feedback, he offered, extends this as a means of knowing the world, as well as providing rich generative musical potential: *'its really a knowledge generation machine in a way'*. *'Coming from computer science, most of the time you start with a clean slate of a blank page - this is the curse of the digital' ... 'so you have to generate in order to get complexity'*. *'Through this interaction, there is so much there already'*. More than a musical device, Bovermann talked about feedback as a *method* or tool - one that helped him understand the world, including the instruments in which it is manifest. With a simple example, he explains how simply turning an audio signal back on itself can reveal details about the system that generates it:

'My audio language of choice was using the internal microphone and feeding it back in through the speakers of the computer, and then using the hands in order to shape the sound. There's a surprising amount of character in that simple loop. Somehow you learn so much about the internal workings of the system - like the combination of the resonating body, of the laptop, the capabilities of the speaker, how close the speaker and the microphone are to each other - and also that crazy limiter that Apple introduced in the chain.'

This, he suggests has become a more general pattern in musical situations: *'it's almost always an accident that it happens. But then I start to get interested. And I think, like, okay, this is something that helps me to understand the situation that we're in.'* Developing an understanding of such a system is embodied and iterative and takes place in moments of exploration. For Bovermann, this exploration becomes narrativised as the performance itself.

One of his feedback instruments, *Half-closed Loop*, is described as an instrument for *'storytelling improvisation'*. By feeding back signals from a physical string in a brass pipe on a wooden board with a range of opportunities for digital and analogue manipulation, Bovermann describes this as a *'fusing'* of performer and instrument into a *'meta-system'* of human-instrument entanglement, which supports a conversational form of improvisation. Talking about performing with *Half Closed Loop* Bovermann shared his approach to performance. Coming to understand the system, his part in it and the states that he and the instrument enter is precisely the basis of performance; *'its an exploration, that I do for me in front of an audience' ... 'a narration of the exploration of this soundscape that this complex system is capable of doing'*. In this context, we discussed the joy of the conversational mode of interaction that feedback systems afford. Highlighting de Campos' mantra *'lose autonomy to gain control'* (De Campo, 2014), and Pickering's cybernetic dancing metaphor (Pickering, 2010) he reframes the idea of unpredicatability: *'I like this idea of dancing with this kind of other complex system, because this is really what it is. For me, it is not about unpredictability. It is more about gaining an idea about this opposite to me, how it might react to what I'm doing. So it's a conversation, really, in some very real way'*.

Many new musical instruments and paradigms talk about the disrupting, dismantling or dissolving of the classical triumvirate - instrument, performer, composer. In using feedback as a core design principle to build instruments, the performance itself becomes an exploration of their capabilities, which even as designed by the performer are not strictly knowable - it *'escapes my capability of grasping it all at the same time'*. In some very real ways, the boundaries between instrument and performer also merge.

Not in the same way as a trumpet extends the vocal tract, but as a coupling of complex systems - that we ourselves become a part of: *'I also started looking into the notion of organisms as this kind of multi-level, multi-layer thing. Like an organism is comprised of other organs, or maybe comprised of other organisms. Not necessarily organism as in human being, or cat, or dog, or something; it could also be a city, you know ... also with these kind of artificial feedback systems that we are talking about, these musical instruments, it's also like creating something that is enough of an organism that it is worthy to poke it so that it is reacting in a certain way. And also creates like a common organism between me and this thing; I'm also an organ, like we are also an organism together, in a way.'*

The points raised by Bovermann reinforce and extend earlier discussions of feedback instruments as tutors in *complexity literacy* (Eldridge, 2022). Not only do we learn about complexity from an engineering perspective (how simple parts can be coupled through feedback to generate complex behaviours), but *experientially* we practice a mode of interaction that is more about *collaboration* than control. We become a part of a larger system and learn to dance within it. In this context feedback instruments are not only *musical* instruments and epistemic tools (Magnusson, 2009), but ontological and ethical playgrounds.

Instruments for developing response-ability and complexity literacy have potential application in wider circles. For example, in dealing with environmental crises, there are increasing calls to adopt socio-ecological systems thinking that 'facilitate dynamic ways of 'interbeing' with one another and the natural world, rather than the (traditional) 'command-and-control' natural resource management' (Fischer, Riechers, Loos, Martin-Lopez, & Temperton, 2021) p.22. This is especially true in enabling the rapid transition needed in sustainable land management. In discussing the changes that are needed for the UN Decade of ecosystem Restoration to succeed, Fisher et al advise that 'land managers have to embrace uncertainty and navigate complexity, constantly expecting new challenges and remaining responsive to them. Underpinned by a desire to care for life, a paradigm of navigating complexity instead of tightly controlling it is especially useful for restoration.' (Fischer et al., 2021) p.22. Land managers need to learn to dance with the complex dynamics of openly evolving landscapes under regenerative and rewilding management regimes. But they have no opportunity for rehearsal and we only have one shot at this: ecosystem integrity evolves over decades, hundreds and thousands of years. Feedback instruments provide an opportunity to become familiar with steering complex systems; getting a *feel* for self-willed systems would bolster their intuition, supporting better decision making as guardians of ecological wild systems.

Boverman's interview also points to the ethical value of feedback musicking in affording an ontological playground for decentering human supremacy. All musical performers respond to their instruments and performance environment to a degree, but the *dynamical autonomy* of feedback instruments demands a shift in mode of interaction that some argue is a difference in kind. More than simply sensitive adaptation, the interaction itself takes on a form of autonomy and couples, or entangles the player and instrument. Bovermann's metaphor of playing with a feedback instrument as a conversation of discovery and response, of 'becoming an organism' resonates with both enactivist accounts of participatory sense-making (De Jaegher & Di Paolo, 2007) and new materialist accounts of responsibility, bringing an ethical dimension to our activities. In training us to be *sensible* and *responsive* to other agencies, we enact - and actively practice! - a relational attitude of 'response-ability', an attitude that shifts our mode of interaction with the world from control to care. An interesting question is whether practicing this relational mode of being (getting to know, becoming-with)

on-stage, might influence our interactions with other beings (Haraway, 2008) off-stage.

The current feedback renaissance arguably reflects (and feeds!) a wider cultural turn - away from a reductionist view of a world-out-there that we aim to control, toward facing the complexities of an uncertain world (see e.g. (Henig & Knight, 2023)) that is co-constituted through our interactions other agencies. As Eldridge notes (Eldridge, 2022) - computer musicking in general and feedback musicking in particular provide a rich space to explore alternative ways of being in the world, including ways of being that may lead to more positive futures. This is a kind of speculative fiction, or applied philosophy (Magnusson, 2019) where we can learn about the world and rehearse ways of becoming-with and making-with the world through music practice. In this sense, feedback musicking provides a rich ethico-onto-epistemic (Barad, 2007) playground - a compound construction that points to the idea that our ways of knowing and being are inseparable from our ethical position.

3.7.2. *Challenges*

- Investigate the potential of feedback instruments as tutors of complexity literacy.
- Follow intersections with enactivism and participatory-sense making, as rich theoretical bases for interaction design and understanding musical experience, and as an application domain for feedback musicianship as a philosophical instrument.
- Investigate the extra-musical effects of playing feedback instruments. Does the conversational mode of interaction nurtured by feedback musicianship spill over into interpersonal or other extra-musical interactions? Does the experience change our way of being with others in the world?
- How might simple feedback instruments be useful educational instruments in other domains, learning to steer complex adaptive systems, or generating awareness or the capacity to deal with uncertainty?

3.8. *Research Methods*

Feedback Musicianship is being explored from a range of research perspectives, and as such, researchers have employed a broad variety of methods. This section will review the research methods that have been used in published studies, looking at the advantages, shortcomings and trends, before suggesting research challenges. Approaches fall roughly into categories of practice research, design research, surveys, interviews and technical analyses. Methods are largely qualitative with a few exceptions. Most studies focus through the lens of the instrument, and then extrapolate outwards into wider feedback musicianship. A minority of studies do the opposite and look at the field from a wide perspective.

Beginning with studies that focus through instruments, a practice research approach can be seen, for example, in Pultz-Melbye’s research on the feedback-actuated double bass (Melbye, 2021; Melbye & Waters, 2023), offering an account of the design of the instrument, and a theoretically-grounded reflection on experiences as a player. Ulfarsson, as a designer of an instrument with multiple players, takes a cross-cutting, interview-based approach to exploring player experience (Ulfarsson, 2019). We can see practice research accounts that veer more towards *design research* methods (Gaver, 2012), reflecting on documentation and experience of building an instrument, for example Di Scipio’s account of processes (Di Scipio, 2022) in the EcoSystemics project or the development of Eldridge and Kiefer’s Feedback Cello’s Eldridge and Kiefer (2017). Some studies have focused more specifically on application and evaluation of particular

algorithms or techniques: Sanfilippo’s study of complex adaptive systems (Sanfilippo, 2021), Mudd’s work on chaotic systems and physical modelling Mudd (2019), or Kiefer’s CoFlo algorithm (Kiefer, 2023; Kiefer et al., 2020).

Another approach is to reflect on the application of a taxonomy or external framework to feedback musicianship. For example Tomasi (2022) applies a taxonomy of emergence to describe the development of a musical piece. There are some projects that follow a more HCI-inspired approach of user studies; Armitage et al. (2022) evaluate the Proto-Langspil, with the instrument as a boundary object that focuses discussion in *encounters* between players, while also carrying out short field studies, analysed through surveys and interviews. Another example is Petersson and Ek (2022), who interviewed players working with the Sinewo0D system. A less common approach is mathematical analysis of some aspect an instrument, for example Brandtsegg (2022) carries out a formal analysis of the acoustic modes of his plexiglass plate instrument.

A smaller group of studies approach feedback musicianship from a long perspective rather than focusing on a particular instrument or technique. Magnusson et al Magnusson et al. (2022) use thematic interview analysis to draw on the experiences of participants in the FMN, and during the activities of the FMN we used group discussion methods (e.g World Café) (Fouché & Light, 2011) to draw on a range of experiences. Other studies follow a literature-based review approach, e.g. (Sanfilippo & Valle, 2013). Mudd (2017) follows an HCI-informed approach to surface broad insights into musicianship with nonlinear dynamical systems, with a combination of comparative empirical studies and ethnography.

Drawing these threads together, we can see the dominance of qualitative research methods. This is perhaps due to the complex and often unpredictable nature of feedback musicianship, that makes it challenging to reduce, isolate or compare phenomena quantitatively. For example, it’s hard to follow task-based evaluations Wanderley and Orio (2002) which are common in NIME research, when instruments cannot be guaranteed to consistently behave in a particular way.

There are several studies that draw on complex systems frameworks (cybernetics, adaptive algorithms, complexity), it follows that feedback musicianship studies may benefit by borrowing from complex systems methodologies, for example participatory systems mapping (Barbrook-Johnson & Penn, 2022). Looking for other potential opportunities from new and emergent methods, we might look to entanglement HCI and micro-phenomenology. Entanglement HCI (described as the fourth wave of HCI) acknowledges and examines the complex web of relationships between instruments and other agents (Morrison & McPherson, 2024). Micro-phenomenology (Petitmengin, Remillieux, & Valenzuela-Moguillansky, 2019) is an interview technique that helps to access fine-grained details of lived experience and looks to have great promise for post-analysis of musical activities (Reed et al., 2022). Both of these methods have yet to be thoroughly explored in feedback musicianship.

3.8.1. Challenges

- Find and adapt evaluation methods that help to develop deeper insights into the experience of playing feedback instruments, for example from complex systems research, HCI and micro-phenomenology.
- Review quantitative methods for evaluating player experience, focusing on their suitability of feedback musicianship.
- Investigate practice research methods as applicable to feedback musicianship.

4. Summary

A principle intention of the FMN project was to set out an agenda for future research in feedback musicianship that we summarised in this report. In doing this, we've also highlighted the rich history of the field, the wealth of current activity, the diversity of unique instruments being developed around the world, and the variety in approaches to current musical practice and research. The challenges we've set out arose from discussions and activities that took place during the network, and also on a set of short case studies with practitioners. A common ground of research challenges is the framing of these musical instruments as complex systems, which in turn suggests the need to encourage diffractive approaches and a 'systems thinking' mindset in order to support feedback and multistable musicianship practices as they evolve in the future. At a time when music is being radically devalued by our institutions we have also celebrated the value of these instruments in providing a unique means to imagine, invent and rehearse ways of being in- and making-with the world that bolster complexity literacy and decentre humans, tooling us up for navigating uncertain futures with care, imagination and joy.

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Research Ethics

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