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Into the Deep End — Developing an informative interactive online tool for improvised performances in electronic music

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Michael Stark BA

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Abstract

This thesis documents the conceptual development and practical implementation of an interactive, informative online application focused on improvisation in electronic music. It begins with literature-based research that examines a broad range of topics related to musical improvisation, including its historical, societal, cognitive, and aesthetic dimensions. The scope is then narrowed to explore the expanded possibilities afforded by technological innovations within electronic music improvisation. To deepen the understanding of key characteristics specific to this practice, a series of comparative audio analyses are conducted, highlighting contrasts in timbre, rhythmic structure, and melodic content between acoustic and electronic improvisations. The insights gained from both the theoretical research and quantitative analyses serve as foundational elements in the development of the final application. This includes a set of prompt-like impulse statements, inspired by the literature review and the outcomes of the audio analyses, as well as an online instrument that enables users to translate cognitive input into immediate sonic output. Through this approach, the thesis aims to bridge practical and theoretical perspectives in the fields of digital humanities and musicology, while also offering a novel lens on improvisational practices in electronic music.

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Chapter 1 — Introduction

Being *"thrown in at the deep end"* or *"jumping in at the deep end"* is an idiom in the English language that describes the experience of facing an unfamiliar or entirely novel situation without the opportunity to develop a coping strategy in advance. ("jump in at the deep end" 2025).

One such scenario is the act of musical improvisation. Although it is difficult to define precisely — as will be demonstrated in the early chapters of this thesis — improvisation consistently involves elements of spontaneity and unpredictability. These elements may range from minor decisions, such as selecting a tempo on the spot, to more substantial acts, such as composing an entire piece in real time.

In the field of electronic music, the spontaneous and unpredictable nature of improvisation is amplified by the use of technological innovations and instruments that often lack established histories, conventions, or standardized performance techniques. Moreover, improvisation in this genre is not confined to traditional concert settings; it frequently occurs in non-performative environments such as studios. Additionally, performers are not limited to interacting with other human musicians — they can now engage with musical machines as improvisational partners (Mazierska 2018).

Taken together, these factors make electronic music a particularly compelling domain for research, especially when investigating how its novel features shape and heighten the sensation of "jumping in at the deep end."

As the title of this thesis suggests, the project offers a distinctive perspective on the experience of improvisation. Rather than simply examining the notion of being "thrown in" or "jumping in" *at* the deep end, it seeks to explore what it means to consciously dive *into* that metaphorical space. This is accomplished through the conceptualization and development of a specialized digital tool designed to facilitate novel forms of interaction with improvisation in electronic music. The tool takes the form of an interactive web application that presents users with prompt-like impulse statements, the content of which is informed by a comprehensive literature review and comparative quantitative audio analyses. The application is further enhanced by an integrated touchscreen instrument that enables users to immediately translate the cognitive impulses into practical musical expression.

As this project is situated within the field of Digital Humanities, it aims to integrate the diverse dimensions that define the discipline. Rather than limiting itself to a media-focused investigation of improvisational practices across cultures and music history — with particular emphasis on electronic music — nor restricting its scope to a large-scale analysis of audio files from various musical improvisations, the work also avoids functioning solely as a technical account of the development of the digital tool. Instead, it seeks to synthesize these elements into a cohesive whole. By doing so, the project aspires to offer a more comprehensive perspective on the subject matter and contribute a distinctive approach that reflects the interdisciplinary nature of Digital Humanities.

In order to translate this conceptual framework into practice and reflect the three core aspects outlined above, the thesis adopts a tripartite structure that highlights the project's interdisciplinary scope. The first two sections serve as its theoretical foundation, while the third functions as a detailed documentation of the design process, technical implementation, and iterative refinement of the final application — including considerations of UI/UX research.

The first part of the literature-based research focuses on general aspects of musical improvisation. In attempting to define the field, it explores the boundaries between improvisation and composition as closely related disciplines, providing historical examples that illustrate how this relationship has evolved over time. This discussion also involves an examination of the role of performance within the context of this duality. Additionally, the section investigates various forms of improvisational practice, drawing on Derek Bailey's distinction between idiomatic and non-idiomatic improvisation (Derek Bailey 1980).

The bespoke characteristics and fluid nature of improvisational practices are further examined through a concise historical overview of improvisation in music. This section highlights key concepts and developments across different periods, beginning with practices in Western medieval music, such as the improvisation of accompanying voices for pre-composed spiritual chants. It also considers early polyphonic music and the codified rule systems that guided improvisational behavior within that context.

Building on this foundation, the discussion then turns to the Baroque era, which marked a significant turning point in the history of musical improvisation. The concepts of *basso continuo* and counterpoint are analyzed as central elements that reflect this shift. During this period, improvisation evolved from merely supporting melodic lines to

contributing to a more structured, harmonically driven musical framework — one that more closely resembles modern chord-based approaches (Moelants 2014).

The historical overview continues with the Classical and Romantic periods, during which improvisation underwent further transformation. This section examines two contrasting approaches: the embellishment of specific, limited sections within a composition versus the extemporization of entire pieces based on established formal structures, such as the sonata form. Furthermore, the discussion explores the emergence of aesthetics as a philosophical discipline and its influence on the role of improvisation in musical practice.

This is followed by a closer examination of the significant shift that jazz music introduced to the practice of improvisation. The focus is placed on how the genre challenges established conventions and traditions through its improvisational approaches. In addition, the discussion considers the role of canonical pieces in shaping a performer's relationship to the genre's musical heritage.

The final form of improvisational practice explored in this historical overview is the free improvisation movement that emerged in the late 1950s and 1960s. This section identifies key figures and collectives associated with the movement, highlighting their efforts to challenge and transcend established musical conventions.

The discussion then broadens to examine improvisational practices in a range of other musical genres and global traditions, with a particular focus on non-electronic forms. This includes an analysis of improvisation in genres such as rock and noise music, as well as an investigation into its role in classical Indian music and the presence of improvisational elements in traditional African musical practices.

To further expand the understanding of improvisation, a subsequent section of the literature-based research examines the cognitive, societal, and aesthetic dimensions of musical improvisation. This analysis begins by addressing ethical considerations, political agendas, and power dynamics that may arise within improvising ensembles.

The discussion then shifts to the competencies essential for successful improvisation. These include the practice of active listening, the importance of a shared musical vocabulary, and the ability to draw upon common historical references within the musical tradition.

The analysis subsequently turns to the cognitive dimensions of musical improvisation. This section presents several studies that investigate the complex interplay of cognitive and neural processes — including motor coordination, auditory feedback, and emotional regulation — in generating appropriate responses within improvisational contexts.

Additionally, the phenomenon of flow states is examined as a critical element in the improvisational experience.

The section concludes with a discussion of the unique aesthetics associated with musical improvisation. It considers the emergence of aesthetics as a distinct philosophical discipline and its influence on the recognition of improvisation as a legitimate musical practice alongside composition. Furthermore, it explores attempts to articulate the specific aesthetic qualities that arise from the spontaneity and immediacy inherent in improvisational performance.

The final part of the literature-based research focuses specifically on improvisation within the genre of electronic music. This section begins with a brief historical overview of electronic music, followed by an examination of fundamental technical principles of audio synthesis. This is because the synthesizer is not only a pivotal element in the evolution of electronic music but also a key component of the digital application developed in this project. The discussion concludes with an exploration of various elements that characterize improvisational practices in electronic music.

The historical overview of electronic music provides a concise examination of the genre's development in relation to the technological advancements of each era. It highlights the emergence of early electronic instruments such as the theremin, as well as the use of tape machines and their integration into electronic music studios. These observations on technological innovations are then contextualized through the contributions of key figures active during those periods. The section concludes with a brief discussion of contemporary developments, including algorithmic composition and the evolving role of AI-generated audio in the future of electronic music.

The following discussion on audio synthesis examines the core components and their respective roles within a synthesizer instrument. It outlines the fundamental concepts of oscillators, filters, envelope generators, modulators, and audio effects including distortion and delay. The focus then shifts to the innovative interface designs introduced by synthesizer pioneers such as Don Buchla and Robert Moog, emphasizing how these unconventional approaches expanded the creative possibilities of electronic music performance.

The section concludes with an overview of key characteristics associated with improvisational practices in electronic music. These facets include the prevalence of improvisation in studio environments rather than traditional live performance contexts, the role of bodily gestures in relation to unconventional instruments, and the significance of

shared interaction with electronic instrument interfaces. Additionally, the discussion addresses the emerging dynamics of collaboration with non-human agents, such as music robots and computer systems. The section closes with reflections on the unique sonic possibilities enabled by digital synthesis within computer-based environments.

All of these discussions share a common thread — they are both focused and concise. Their primary purpose is to establish the theoretical foundation for the subsequent development of the online application. Rather than delving deeply into any single aspect, they aim to broaden the scope of perspectives and provide a comprehensive framework for understanding the key concepts.

The same principle applies to the quantitative audio analyses, which constitute the second part of this thesis. These analyses are designed to highlight the differences between improvisation in the acoustic and electronic music domains. By comparing two contrasting audio examples, the analyses emphasize these differences and extract key reference points that will inform the prompt-like impulse statements in the final application.

The analyses conducted encompass several key aspects of the two pieces, beginning with an examination of the rhythmic elements, including the detection of tempo, beats, and onsets. This is followed by a spectral analysis that explores the timbral components of the pieces, presented through spectrograms and visualizations of Mel-frequency Cepstral Coefficients (MFCC) and the spectral centroid. Finally, the differences in the dynamic range of the two pieces are analyzed. All of these processes are carried out using the Python programming language and the Librosa library, as it provides essential tools for conducting the aforementioned analyses efficiently and effectively.

The third part of the thesis documents the design and development process of the final application. The discussion begins by examining the practice of building digital tools and software solutions as a form of scholarly engagement within the field of Digital Humanities. Particular emphasis is placed on how the act of making contributes to knowledge production, contrasting this approach with traditional theoretical inquiry. The thesis also briefly references the ethos of “more hack, less yack”, as articulated during the 'un-conference' THATCamp (Nowviskie 2016) highlighting a shift toward hands-on, practice-oriented scholarship. This introductory section concludes by addressing the criteria that digital tools must meet in order to be considered relevant and valuable within academic contexts.

Subsequently, the section contextualizes each component of the application in relation to its scholarly and artistic references. The prompt-like impulse statements draw inspiration

from *Oblique Strategies*, a creative tool developed by Brian Eno and Peter Schmidt (Eno and Schmidt 2015). The process of generating these statements is documented and situated within the theoretical framework established in the literature-based research, as well as the insights derived from the quantitative audio analyses presented in the earlier sections of the thesis. The instrument component is a reinterpretation of the early electronic instrument, the Theremin, while the visual structure of the landing page is informed by the layout and design principles found in John Cage's *Lecture on Nothing*. (Cage 1961).

The thesis proceeds by documenting the design process conducted using the software *Lunacy* ("About Lunacy," n.d.). This is followed by an account of the application's technical implementation, which was realized using HTML and CSS — specifically employing the Bootstrap framework (contributors, n.d.) — along with JavaScript. To enable audio functionality and provide an interactive user interface, the development process made use of two JavaScript libraries: Tone.js ("Tone.Js," n.d.) and P5.js ("Home | P5.Js," n.d.).

The third part concludes with a User Interface and User Experience (UI/UX) research component. It begins by examining the relevance of UI/UX research within the context of Digital Humanities, highlighting its role in shaping meaningful interactions between users and digital tools. Subsequently, a questionnaire is designed and distributed via Google Forms. The collected responses are analyzed and incorporated into a final discussion on how the findings may inform potential future iterations of the application.

Chapter 2 — Fundamental Aspects of Musical Improvisation

2.1 Overview

This introductory chapter explores the fundamental concepts underlying the phenomenon of musical improvisation. The discussion is divided into three sections. The first section examines various attempts to define the field of musical improvisation, including an analysis of its boundaries with composition and the ways in which the two practices intersect.

The second section investigates the historical and global evolution of improvisational practices, with an examination of various musical genres and the manifestation of improvisation within these specific styles.

The final section addresses cognitive and philosophical aspects of musical improvisation. Topics covered include interpersonal connections established through improvisation, psychological phenomena such as flow states, and aesthetic considerations associated with the practice.

2.2 Attempts at Defining Musical Improvisation

Defining musical improvisation presents the challenge of distinguishing it from the act of composing. Bruce Ellis Benson offers a broad and inclusive perspective in his book *The Improvisation of Musical Dialogue: A Phenomenology of Music*. He suggests “that the activities that we call 'composing' and 'performing' are essentially improvisational in nature, even though improvisation takes many different forms in each activity” (Benson 2003, 2).

Benson derives this argument by first challenging the traditional notion that performers must reproduce a given piece of music as faithfully as the composer intended. This conventional approach is often justified by the desire to preserve the integrity of the work, prohibiting any deviation from the composer’s original intentions. It also frames the performer merely as an extension for executing the composer’s will.

Moving away from these rigid ideas, Benson shifts toward a more open and inclusive definition of improvisation. He contrasts the works of Rossini and Beethoven to illustrate this perspective. While Beethoven's approach aligns more closely with the ideals of *Werktreue* (fidelity to the work), Rossini viewed his compositions as flexible guidelines adaptable to performance contexts. These adaptations often included choices regarding ornaments for specific musical phrases, which were left to the discretion of the performer (Benson 2003).

Similar ideas can be found in Alperson's (1984) reflections on the topic, where he also raises the question of how the act of musical improvisation is shaped and whether there is a clear distinction to be made from composition. The author begins his observations by examining the differences between performance and composition. He makes the point that one cannot exist without the other, as they are logically interdependent. The former requires an underlying score, while the latter — even if only in the composer's imagination — necessitates some form of sonic representation. He then synthesizes these observations, wherein improvisation is seen as the spontaneous creation of a musical work where both the performative and compositional components are united.

Building on this conceptual tension, Bailey (1980) introduces a new binary framework for understanding improvisation. In his analysis, he distinguishes between idiomatic and non-idiomatic types of improvisation. The former is associated with a specific musical style or tradition, such as jazz or flamenco, whereas the latter follows a more freeform approach. This latter style is often found in freely improvised music that emerged in the early 1960s. This type of improvisation represents a departure from formal training, institutional structures, and Western musical notation. It also serves as an entry point into the socio-political dimensions associated with the groups that performed it, particularly in its early stages.

2.3 Musical Improvisation Through History

These definitional questions stem from the long and fluid history of musical improvisation. To illustrate the diverse and evolving nature of the practice, the following section will examine key concepts of improvisation across different historical periods, cultural contexts, and musical genres.

2.3.1 Medieval and Renaissance Improvisation

Improvisation held a central place in the music of the European Middle Ages, influencing various aspects of music creation, whether entirely extemporized or involving the expansion of notated material.

Early examples emerged during the Carolingian Renaissance, when music composition was predominantly controlled by the church. As a result, musical pieces primarily consisted of spiritual chants, and improvisation was employed to create additional

voices over monophonic (single-voiced) material. The rigid rules governing these accompanying voices were transmitted orally within monasteries for educational purposes.

One notable example that transcends the static nature of early polyphony is the *Vaticanum Organum Treatise* from the early 13th century. This treatise initially presents several key principles, followed by a collection of written “two-voice progressions that appear to be intended for memorization” (Smilansky and Lewon 2021, 319). These progressions were transcribed from extemporizations by professional singers and served as foundational building blocks for the development of personal style, paralleling later approaches to acquiring improvisational skills (Smilansky and Lewon 2021).

Another perspective on improvisation in early western music is opened by Bechtel (1980). As previously demonstrated, Renaissance music often provided information on guiding tonal structures, while details such as tempo and instrumentation were frequently omitted, affording contemporary performers interpretative freedom. This phenomenon stems from the historical context where composers and performers were frequently synonymous. Bechtel also documents numerous rule catalogs from this period that governed various aspects and techniques of improvisation. These guidelines — similar to the aforementioned *Vaticanum Organum Treatise* — encompassed instructions on selecting a primary melody, choosing the appropriate ornaments in playing or restricting the number of improvised voices within an ensemble.

2.3.2 Baroque Improvisation: Counterpoint and Basso Continuo

The Baroque epoch marks a turning point for improvisation, as it witnessed a transition from creating harmonies to support leading melodic voices to a chord-based approach. It is important to note, however, that the concept of the "chord" as understood today did not exist at the time (Moelants 2014).

Two central terms are essential for understanding the improvisational practices of this period: *counterpoint* and *basso continuo*.

In its essence Counterpoint is a set of rules governing how melodic layers are supposed to interact with each other. It therefore employs “compositional devices such as consonance, dissonance, suspension and resolution to create a dynamically shifting relationship between the layers that create tension and release.” (Mulligan 2024, 6).

Basso continuo, on the other hand, describes the practice of structuring accompanying voices over a given bassline. This was typically performed on keyboard instruments and often

involved improvisation (“Basso Continuo | Baroque Music, Accompaniment & Improvisation | Britannica” 2024).

During this period, these principles were applied in improvisational contexts by filling out the middle voices of a polyphonic piece, with the outer voices serving as guiding lines — a procedure known as *ex centro* (Moelants 2014).

2.3.3 Improvisation in the Classical and Romantic Eras

In the late 18th and early 19th century musical improvisation oscillated between — and at times united — two major practices. The first involved altering and embellishing a specific section of a composition for a brief period. The second focused on developing melodic and rhythmic motifs within a defined musical structure, such as the fugue.

A central example illustrating the fundamental difference between these practices is Ludwig van Beethoven's approach to improvisation. Although, as will be discussed later in this chapter, Beethoven's use of improvisation within his own compositions was restrictive, contemporaries described him as a highly skilled improviser. He distinguished clearly between the two primary streams of improvisation. For Beethoven, true improvisation involved "the presence of an extended and articulated organization of musical ideas," as opposed to the temporary embellishment of pre-existing material (Carone 2017).

The sonata form was another structure well-suited to such improvisational undertakings. Carl Czerny, Beethoven's contemporary and an accomplished pianist and teacher, provided extensive insights into improvisation within this genre. He advocated for training in the improvisation of rondos, scherzos, variations, and slow movements — essentially all the individual movements of a sonata — as a path to achieving virtuosity. Czerny’s detailed advice included guidance on the development of primary and secondary motifs, key transitions, and the degree of freedom appropriate to different sections of an improvisation (Eggers and Lehner 2021).

Advancing further into the 19th century marks a pivotal juncture in the trajectory of improvisation. The ascendancy of Romanticism, the emergence of aesthetics as a philosophical domain, and the overarching emphasis on notated composition contributed to a decline in improvisatory practices. However, Gooley (2018) introduces a counter narrative to this development. He underscores that despite this trend, many composers continued to utilize piano improvisations as a means of generating musical ideas. Additionally, Gooley introduces the concept of “improvisation imaginary (Gooley 2018, 16)”. With this the author highlights

the Romantic-era composers' aspiration for improvisation, albeit absent from concert settings of the period. Moreover, Gooley's research elucidates how contemporary musicians, particularly those versed in Romantic and classical repertoires, are reintroducing improvisation into modern concert venues. This resurgence is not solely driven by marketing novelty but also by the potential for performers to distinguish themselves in an oversaturated market.

2.3.4 Jazz and the Expansion of Improvisation

A significant shift in the perception and practice of improvisation emerged with the rise of jazz music. Contemplating the term heterophony, Benson (2006) delivers an analysis of the origins of jazz and improvisation in jazz music. In this observation the concept of heterophony stands in stark contrast to the ideals of ancient Greek, Renaissance and Baroque improvisation where only one voice was allowed to improvise over a given tonal material. In contrast, early jazz — and later developments in the genre — allowed multiple instruments to interpret and embellish melodies simultaneously. This departure from tradition is also reflected in the diverse contributions of ethnic groups, including black, Creole, and white musicians, each bringing unique talents to the table. Especially Black musicians demonstrated exceptional prowess in improvisational playing, while Creole musicians boasted formal training. This was once more extended with the fusion of black and white musicians in the further development of the genre.

This development can often be comprehended via the analysis of canonical pieces or in the case of jazz music through examination of the repertoire of standards. Wren (2022) delivers an attempt at showcasing how these standards serve as the backbone of improvisation in the genre and how the two — the standards and the improvisation — are interdependent. The author begins by acknowledging that while jazz standards are fundamental to the genre's culture, providing reference points for both players and listeners, they are often perceived as constraints by improvisers due to their association with a strict set of rules. Advancing further in his observations he introduces Foucault’s concept of the archive. With this concept in mind he explores how jazz musicians draw upon the accumulated statements of other improvisers over time, engaging in a continuous dialogue with the musical heritage of jazz. Furthermore, he distinguishes jazz from Indian Carnatic music — despite some parallels — and observes how jazz improvisation moved from the

aforementioned orientation centered on altering single melodic lines to an approach where chord changes play a more crucial role.

2.3.5 Free Improvisation and Experimental Approaches

Although jazz had fully matured as a genre, it continued to reference its historical roots and repertoire. However, in the late 1950s and early 1960s, a new evolutionary stream of improvisation emerged. This new improvisational style emerged simultaneously in America and Europe. Spearheaded by figures like Derek Bailey and groups like the Spontaneous Music Ensemble, free improvisation began to establish itself as a “genre in its own right, with associated record labels, media, significant artists, aficionados and performance rituals (Sansom 2001, 29) ”. Sansom (2001) delineates several key driving forces behind this evolution. One such factor was the transformative influence of John Cage in the United States, whose fascination with Zen Buddhism prompted a reevaluation of compositional methods, particularly moving away from conventional approaches. Additionally, there was a growing discontent among jazz musicians, weary of repetitively regurgitating Hard Bop motifs. In contrast to that, players like Cardew and the AMM embraced a radically different musical ethos, blending Cage's experimental ideas with a heightened emphasis on “emotional intent, impact and response (Sansom 2001, 30)”. Another relevant building block of the genre that the author identifies is the act of “acknowledging and exploring the role and significance of the performer as creator/composer without the dictates of notation, graphic or otherwise (Sansom 2001, 30)”.

2.4 Improvisation in Non-Western Musical Traditions

Beyond Western traditions, improvisation has long played a central role in various musical cultures worldwide. As described by Bailey (1980), Indian classical music can be coarsely divided into two main traditions. Hindustani, which can be found in the north of India, and Carnatic, a musical tradition mostly occurring in the south of India. Due to the dominance of Hindu culture in the south, the Carnatic tradition very heavily relies on traditions and Sanskrit texts. In contrast to that the northern tradition of Hindustani music — constantly being exposed to migration and political change — shows to be much more open to improvisation. Overall it is essential to note that improvisation holds significant importance in Indian classical music, as described with varying intensity. Derek Bailey highlights the central framework for both traditions, known as the raga. Within this framework, musicians engage

with elements such as sruti and svara, which define intervals, as well as tala, a rhythmic structure. These components serve as the foundational building blocks of Indian classical music, and their variability renders it a fertile ground for improvisation.

In his article for music software company Ableton, artist and essayist Adam Longman Parker (better known by his stage moniker Afriqua) (2022) identifies improvisation as one of the primary elements of African music. This is strongly supported by the fact that African music is transferred orally from generation to generation, making the act of performing vital for this process. Although these performances create a space for improvisational practice, they also adhere to traditions and therefore certain structural standards.These musical structures, such as rhythmic patterns or melodic material, do not only serve as aforementioned guidelines, but also help constitute the identity of different tribes (or similar cultural entities). Also, they offer a good potential to point out parallels to how improvisation was handled in Western music in for example the Renaissance period and how it is still treated in jazz music, with many improvised solos referencing certain traditions and jazz standards serving as guiding structures.

2.5 Improvisation in Contemporary Genres

But not only in several other regions of the world one can find improvisational practices, with the rise of new technical possibilities and a novel form of popular music, improvisation emerged in other musical genres as well. Especially in rock music a lot of players improvised (and still improvise to this day) in a very virtuosic manner. Learning from and referencing jazz as well as classical players and worldwide ethnomusical traditions, they developed (and develop) unique genre shaping customs. Besides offering perspectives on aspects like class, race and journalistic dialogue associated with rock music in the 1960s, Brackett (2020) identifies exactly these improvisational activities as one of the key factors of why rock music played the role it played at that time. The author does not only offer a wide variety of examples of how musicians of that period incorporated elements from classical Indian music like drones or guitar lines reminiscent of ragas into their works. He also states that improvisation served as a distinction between older, more pop music oriented forms of rock music and newer, artistically freer versions of the genre.

An even freer approach to improvisation can be found in Noise music. Drawing from all the aforementioned traditions but also incorporating electronic devices (often not even

intended for musical use), Noise music marks another crucial outpost when describing the field and history of improvisation. In his dissertation Igarashi (1997) on the one hand offers an elaborate analysis of how Noise music relates to other art forms labeled as post-modern and on the other hand gives an extensive overview of the constituting factors of the genre. The author identifies particularly the eclectic use of elementary musical units, like harmonic and melodic material as well as varying timbres, and the act of unintentionally collaging unrelated materials together as two key factors in the understanding of Noise music. As previously noted, referencing different musical traditions is a common practice in improvisation. In Noise music, this practice reaches new heights through the incorporation of recorded material. This utilization of musical quotes through new technology and the ability to combine them in seemingly arbitrary ways underlines on the one hand the eclectic character of the genre. On the other hand it opens up the door to investigating improvisatory practices in electronic music, which utilize a close interplay with technological devices.

2.6 Cognitive, Societal and Aesthetic Aspects of Improvisation

As demonstrated above, musical improvisation encompasses a wide range of facets. However, its significance extends beyond historical, global, and stylistic characteristics, influencing various fields of research. The following sections will examine the impact of musical improvisation on social behavior, its cognitive implications, and the distinct aesthetic principles inherent to the practice.

2.6.1 Musical Improvisation between Ethics and Utopian Ideas

Besides developing musical skills, improvisatory practices also provide a space for the establishment of ethical guidelines. These guidelines often manifest in the formation of improvising collectives, where equality among performers and the capacity for musical autonomy are prioritized. Furthermore, the cultivation of individual autonomy fosters the development of a personal artistic voice.

The principle of equality extends even further in the context of teaching improvisation, as it necessitates a transformation in the traditional roles of teachers and students. Teachers are no longer mere transmitters of knowledge but rather facilitators who provide material tailored to students' areas of interest. Consequently, students are encouraged to move beyond passive learning, becoming actively engaged and reflective participants in their own educational process (Lange 2011).

More socio-political aspects of improvisation, especially in groups freely improvising music together, are a recurring topic in the interviews conducted by Childs et.al. (1982). The narratives found there range from anarchistic ideas rooted in egalitarian music making without pre-written rules to consciousness expanding group experiences — that were part of the (sub-) culture at the time — to societal utopia written into such conglomerates of musicians.

Another connection of improvisational abilities from the musical realm to life outside of musical performances is discussed by Toop (2008). Before delving into a history of his own improvisational practice in various contexts he attests to humanity the need to "learn to improvise, to cope with random events, chaos and accident in order to survive even the most mundane encounter (Toop 2008, 1)". In his reflections on the field he also picks up societal narratives when talking about the power dynamics within a group. Toop states that these are needed to balance the common objective of creating a piece of music together while still retaining individual habits of innovation and artistic expression.

2.6.2 Competencies of Musical Improvisation

In addition to its ethical dimensions, improvisation is a craft that requires several distinct skills. Cobussen identifies three essential competencies for successful improvisation, demonstrated in the 1992 recording of the *Baltic Suite*. He argues that active listening, a shared musical language, and knowledge of musical history are crucial elements, all of which are exemplified in this recording (Cobussen 2017).

The first competency, active listening, involves the ability to pass musical motifs among different improvisers throughout various solos. Cobussen emphasizes that this requires players to remain in an active state of awareness, enabling them to make spontaneous decisions about whether to accept or reject musical contributions from others.

The second competency is the ability to communicate in a shared musical language. This entails a collective understanding of appropriate stylistic choices, including the selection of notes, harmonies, and rhythms.

Cobussen extends this idea further with the third competency: a shared knowledge of musical history. He highlights an instance from the *Baltic Suite* where James Brown's hit song *Sex Machine* is quoted. Due to the ensemble's common familiarity with this tune, all members are able to join in seamlessly, contributing to a coherent and musically meaningful improvisation (Cobussen 2017).

How the player's relationship to these shared musical languages evolves over time is examined in a study by Daikoku (2024), which investigates the "temporal dynamics of uncertainty and surprise" in jazz improvisation. The study suggests that improvisation involves both predictable and unpredictable elements, leading to prediction errors — instances where expectations about the next note are violated — and varying levels of certainty regarding the occurrence of these errors during a performance.

To test this hypothesis, the study employs a Hierarchical Bayesian Statistical Learning (HBSL) model to "analyze 456 jazz improvisations spanning 1905 to 2009, performed by 78 distinct musicians" (Daikoku 2024).

The findings reveal that the temporal dynamics of uncertainty and surprise strongly correlate with shifts in musical eras throughout the 20th and 21st centuries, indicating that musicians are influenced by key cultural and historical phenomena of their respective periods. In contrast, the acoustic features (characteristics of the waveform) of these improvisations — also examined in the study — exhibit relatively little variation over time (Daikoku 2024).

2.6.3 Cognitive Processes involved in the Practice

The unique cognitive processes involved in responding to unforeseen scenarios in improvisational contexts present a compelling subject for cognitive science research.

Shedding light on these aspects of improvisation, Dean and Bailes (2014) explore the intricate cognitive mechanisms that underpin musical improvisation, offering a comprehensive exploration of how musicians navigate the spontaneous creation of music. The research particularly highlights the neural processes involved in perceiving and producing sound. Through a multidisciplinary approach that intersects cognitive science with musical analysis, Dean and Bailes analyze the roles of memory, perception, and skill in the improvisational process. In their paper they also illuminate the dynamic interplay between conscious and unconscious cognitive processes, emphasizing the significance of motor skills, auditory feedback, and emotional states in shaping improvisational outputs. Equal to preceding sections of this literature review, Dean and Bailes also focus on the collective effort of improvisational practice found in group improvisations. They observe interactions among co-improvisers, prompting inquiries into leadership functions and cooperative behaviors during interruptions.

These assumptions of complex interplay between several cognitive and neural mechanisms involved in the spontaneous creation of music are also developed by Limb and Braun (2008) in their study "Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation ". Their effort constitutes a pioneering endeavor in understanding the field by employing functional magnetic resonance imaging (fMRI) techniques. With these methods they observed the brain activities of jazz improvisers during performances, and were able to investigate the intricate cognitive and neural processes inherent in their practice. Via the outcome of these experiments they were able to identify key brain regions and networks involved in the spontaneous generation of musical ideas and expression. Their research highlights the interplay between regions associated with cognitive control, auditory processing, and emotional regulation, bringing clarity to how musicians navigate the creative demands of improvisational performance.

Another particularly intriguing cognitive aspect of musical improvisation is the phenomenon of the *flow state,* which is often characterized by a simultaneous experience of minimal effort and a high degree of creative freedom.

Neuroscientific research on its correlation with musical improvisation reveals a compelling contradiction. While one might assume that the complexity of events during improvisation would result in "higher activity in brain areas involved in higher-order motor planning and cognitive control" (Landau and Limb 2017, 28), the opposite appears to be true. Studies show that as the degree of freedom in musical improvisation increases, there is a corresponding deactivation of the dorsolateral prefrontal cortex (DLPFC), located just behind the forehead and responsible for cognitive control.

This deactivation allows for greater immediacy in decision-making during improvisation, such as reacting spontaneously to musical gestures provided by fellow performers. Furthermore, this neurological phenomenon aligns closely with the defining characteristics of the flow state, where performers experience an optimal balance between effortless action and heightened creative engagement (Landau and Limb 2017).

2.6.4 Aesthetics of Improvisation

An additional aspect distinguishing improvised music from notated or composed music is its assertion of aesthetic value. This characteristic is exemplified in Hamilton's (2000) observations that analyzes the role of imperfections and their management in practice within the field. Also starting from the binary narrative between composition and improvisation he

simultaneously opens up two new polar opposites with the concepts of an aesthetics of perfection versus an aesthetics of imperfection. This thought is taken further and enhanced by comparing the two to other pairs known in the discourse such as “process and product; impermanence and permanence; spontaneity and deliberation (Hamilton 2000, 170)”. While working through a palette of ideas derived from philosophy and musicology, the author concludes that the concept of an aesthetic of imperfection is rooted in pure spontaneity. While this doesn't entail an entirely unprepared extemporization, it rather involves a series of preparations made by the improviser in advance, facilitating spontaneity. Simultaneously, these preparations introduce a sense of continuity and interconnectedness to the dichotomy between composition and improvisation.

Bertinetto (2013) further explores the aesthetics unique to improvisation by offering a historical perspective on the topic. The author contends that from ancient Greece until the eighteenth century, improvisation held a central and indispensable role in artistic expression. However, its significance decreased following the organization and theorization of art practice. This namely was the emergence of aesthetics as a detached philosophical discipline, the establishment of a formal "system of the fine arts," and the widespread use of typography, which solidified the notion of the artwork. The Romantic era introduced the terms "improvise" and "improvisation," marking a conceptual separation between the act of improvising and its artistic outcomes. While improvisation was initially considered part of composition, it eventually became regarded as an exceptional activity lacking the aesthetic and artistic merits of composed works. Nevertheless, its performative nature continues to challenge conventional distinctions between art and life, providing a platform for social and political engagement.

Chapter 3 — Improvisational Practices in Electronic Music

3.1 Overview

The following chapter examines the characteristics of improvisational practices in electronic music, comparing them to similar modes of play in the acoustic domain. This analysis begins with a brief history of electronic music, followed by an exploration of genre-defining instruments and their underlying concepts. The primary focus is on how these tools — whether analog or digital synthesizers — influence players in their improvised performances. These influences may manifest as novel forms of interaction with instruments or the creation of unique sonic expressions. Furthermore the general role of improvisation in the genre of electronic music will be examined.

To incorporate a quantitative and comparative perspective, several analyses of audio files from different genres will be conducted. These analyses will be carried out using the Python programming language and specifically the Librosa library (McFee et al. 2024). They will include rhythmic analyses such as tempo and beat detection, as well as onset detection. Additionally, time and spectral analyses, including MFCC (Mel-frequency Cepstral Coefficients), loudness, and dynamic range, will be performed. The results will be visualized using spectrograms and chroma plots, and the extracted features will be compared and discussed.

3.2 A (very) Brief History of Electronic Music

To establish a meaningful history of electronic music, it is essential to define the term clearly. For the purposes of this discussion, electronic music will be understood according to the definition provided by Britannica, which states that "for a piece of music to be electronic, its composer must anticipate the electronic processing subsequently applied to his or her musical concept, so that the final product reflects in some way the composer’s interaction with the medium" (“Electronic Music | Definition, History, & Facts | Britannica” 2024).

3.2.1 Before 1945

With the development of new instruments like the Trautonium, Dynaphone, and Theremin, the foundation for electronic music was established. These early instruments relied on electronic components for sound generation and, with the exception of the Theremin —

which is played by altering the electromagnetic field controlling the pitch by hand — featured a keyboard interface. However, unlike conventional keyboard instruments like the piano, these were designed to produce a much more sonically sophisticated range of sounds. Although they gained some popularity between 1918 and 1938, only a handful of composers wrote music for these instruments. In contrast, they were widely used in movies during that time, allowing for the creation of novel soundscapes (Manning 2013).

Other innovative approaches to music creation in the early 20th century can be found in the Futurist movement. In his 1910 work, *Manifesto dei musicisti futuristi*, the Italian composer Balilla Pratella introduced a new aesthetic of musical composition. Criticizing the prevailing academic and traditionalist approaches to composition, Pratella outlined several key features of Futurist music. These include freedom in rhythmic structures, the incorporation of microtones, and the extensive use of technical innovations as sources of inspiration. Pratella also proposed using electronic instruments as means to realize these ideas (Levi 2000).

A further development of these concepts is found in the work of fellow Futurist Luigi Russolo. The painter and amateur musician also criticized the predominantly melodic nature of music at the time as too limiting and advocated for the inclusion of noise in musical composition. To this end, he invented mechanical devices called intonarumori, which were capable of producing a range of noise tones. Although these machines were not electronic instruments, Russolo's theory on incorporating noise into musical composition represents a central building block in the foundational concepts of electronic music (Levi 2000).

Another perspective on innovative ideas in early electronic music is present in John Cage's 1937 talk to an arts society in Seattle. During this presentation, Cage referenced the work of scientist Hermann von Helmholtz, particularly his 1862 book, *Sensations of Tone*. Helmholtz explains that the sonic quality of a sound arises from the interplay between a fundamental tone and a series of related higher tones. The quantity, loudness, and arrangement of these higher tones, or overtones, determine the timbre of a sound. Drawing on this technical approach, which complements his own non-emotional perspective on music, Cage identified four essential qualities of sound: the structure of overtones (timbre), frequency, amplitude, and duration. He later expanded on these by introducing the concept of the "morphology" of sound, which refers to the shape of a sound's onset and decay (Holmes 2002).

All of these aspects form the foundation for the subsequent rise of electronic music. They expand the definition of music while also providing a more precise terminology for

describing sounds. Additionally, these new categories of description, combined with the innovative spirit of the time, serve as key entry points to synthesis, a critical element in the emerging genre.

3.2.2 1945 - 1960

The period following World War II was characterized by two main streams driving the evolution of electronic music. One of these emerged in Paris, where *musique concrète* was developed by Pierre Schaeffer and his group. The other was centered in Cologne, Germany, where a local group of composers and inventors pioneered *elektronische Musik*. Despite the close physical distance, the difference in approach could not have been more different (Manning 2013).

Pierre Schaeffer coined the term *musique concrète* to describe a practice that incorporated a variety of preexisting sound material into musical compositions. His work included experiments with tape recorders and short recordings of a wide range of sounds, which he referred to as "sound objects," as well as extensive reflective writings on the subject. Schaeffer's approach did not rely on traditional Western musical notation but rather focused on exploring the musical potential of otherwise non-musical sounds. In his compositions, he manipulated these found sounds by altering their amplitude envelope — specifically their onset or attack behavior — along with their duration and playback speed. Through this process, he was able to recontextualize the sounds and challenge the listener's perspective (Godøy 2021).

In the early 1950s, the WDR (Westdeutscher Rundfunk) studio in Cologne, Germany, became a hub for a collective of composers and technicians who sought a radical renewal of music, particularly in terms of musical timbre. Unlike Schaeffer's Parisian group, which focused primarily on manipulating tapes of existing material, the Cologne collective delved deeply into the exploration of purely electronic sound generators and early synthesizers. Their work notably included the layering of pure sine tones, known as additive synthesis, and the use of early computers, which became hallmark techniques of the WDR studio. A defining feature of this environment was the collaborative effort within the studio, characterized by a dynamic exchange between technicians, composers, and scientific personnel. This marked a departure from the traditional image of the solitary genius composer, fostering more complex cooperative dynamics and highlighting the need for composers to possess skills beyond traditional music expertise (Iverson 2017).

In contrast to the European pioneers of electronic music, the United States did not

experience a similarly constructive and fruitful development of the genre until the mid-1950s. Although John Cage's tape manipulation work — such as *Imaginary Landscape No. 5* and *Williams Mix* — gained notable recognition, a broad movement comparable to that in Europe did not emerge. Nevertheless, Cage's tape pieces, though influenced by the French and German schools of thought, opened up new horizons in composition. Fascinated by Chinese philosophy and the *I Ching*, Cage began incorporating non-deterministic principles into his compositions.

Several key narratives can also be identified in the development of electronic music during this period: the interdependence with technological innovations, the incorporation of non-musical sounds into compositional processes, the emergence of composition as a collective practice, and the introduction of non-deterministic principles into musical composition.

3.2.3 1960 - 1980

The following two decades marked a period of departure and reorientation in the evolution of electronic music. Whereas electronic music had previously been confined primarily to classical music circles — and existed mainly as tape productions or radio broadcasts — it began to reach a wider audience and make its way onto the stage.

Although John Cage's efforts to bring electronic instruments, tools, and production processes to the stage were pivotal to the development of electronic music at the time, the German group around Karlheinz Stockhausen also pursued similar initiatives. Stockhausen, associated with the WDR Studio in Cologne, Germany, pioneered three significant works of electronic music — *Mikrophonie I*, *Mikrophonie II*, and *Mixtur*. These compositions not only employed tape recorders to play back pre-recorded material but also utilized microphones, various filtering techniques, and two modes of synthesis alongside acoustic instruments. The two synthesis techniques employed were subtractive and additive synthesis. The former technique involves altering a complex source material by removing certain frequency bands, while additive synthesis adds harmonic content to simple frequency content, using strategies like ring modulation[1] (Manning 2013).

The move to performing electronic music live was fueled by the easy accessibility of electronic parts like transistors and the following ability to produce machines and instruments that were "lightweight, affordable and durable" ("1960–1970," n.d.). This sparked a wave of

[1] A technique which utilized machines that "multiplied two signals (and hence was sometimes called product modulation), with a typically noisy, broadband result ("Ring Modulation & Autoconvolution," n.d.).

instrument and machine development worldwide. Innovations ranged from Paul Ketoff's "Syn-Ket" — a portable synthesizer with three independently controllable sound modules, which was prominently featured in the works of composer and performer John Eaton as well as Ennio Morricone's soundtracks for "Spaghetti westerns" — to the synthesizers created by Don Buchla and Robert Moog ("1960–1970," n.d.).

The instruments developed by the two American pioneers, Don Buchla and Robert Moog, differed significantly in both their approach to synthesis and their design philosophies. Moog's synthesizers were based on filters and subtractive synthesis, while Buchla's instruments employed more experimental approaches, both in terms of synthesis and interface design ("1960–1970," n.d.) These contrasting designs were used to create two of the pioneering electronic music albums of the period.

Morton Subotnick's *Silver Apples of the Moon*, commissioned by Nonesuch Music in 1967, marked the first time an electronic music album was commissioned by a record company. This work exemplified Subotnick's vision of music that did not adhere to conventional time signatures or traditional tonal colors, realized with an instrument designed by Buchla specifically for the composer's needs (Yelton 2017).

Switched-On Bach by Wendy Carlos took a different approach. Recorded just one year after *Silver Apples of the Moon*, this album was also created using a custom synthesizer, this time designed by Robert Moog. However, it reflected a distinct musical and sonic vision. Rather than pushing the boundaries of musical conventions, Carlos aimed to recreate and enhance orchestral sounds using an analog synthesizer. In doing so, she not only popularized the synthesizer among a wider audience but also demonstrated its potential for use beyond the realms of classical and experimental music (Kheshti 2019).

In the 1970s, the German band Kraftwerk laid the groundwork for emerging sub-genres of electronic music, such as techno. Originally founded by Florian Schneider and Ralph Hütter in 1970 in Düsseldorf, Germany, Kraftwerk drew rhythmic inspiration from artists like James Brown and other prominent Black American musicians, while blending these influences with their own distinctly German approach to melody and harmony. Coupled with their fascination with and use of technology, this fusion allowed Kraftwerk to transcend the cultural void left by World War II, which had impacted German identity. As a result, Kraftwerk became a significant source of inspiration for American artists, particularly musicians from Detroit, fostering a broader transnational exchange in electronic music (Robb 2024).

As music technology continues to evolve, the possibilities for realizing sonic visions

expand, and the boundaries of electronic music begin to broaden. This expansion includes the incorporation of electronic instruments into new genres as well as the emergence of new cultural references within electronic music streams. All of these developments are further enhanced by the introduction of digital components.

3.2.4 1980 - today

Although computer music had existed in the decades prior to 1980, it was around this time that it experienced a significant breakthrough, largely due to increasingly powerful microprocessors, as well as the growing accessibility of music programming languages and associated interfaces. This development was further intensified by the introduction of IBM's "personal computer" (PC) to the market, which played a pivotal role in making these technologies more widely available (Manning 2013).

A pioneering instrument of the time utilizing the novel microprocessor technology was the Synclavier. Invented in the late 1970s, it became an industry-standard music production machine throughout the 1980s. Its capabilities included “FM synthesis, sound analysis, sampling, stereo recording and playback on up to 200 tracks, audio editing, video synchronization, and music printing” (“Synclavier,” n.d.). Due to its versatility, the Synclavier was not only prominent in experimental computer music circles but also found its way into jazz and pop music productions, influencing the sound of the era with its distinct sonic characteristics (“Synclavier,” n.d.).

Another genre-defining invention of the time was the MIDI (Musical Instrument Digital Interface) protocol. Introduced in 1983, MIDI enabled communication between unrelated systems, such as computers, synthesizers, and drum machines, regardless of differences in their configuration. With strong industry support from the outset, MIDI provided music creators with an essential tool to overcome the synchronization issues that had challenged earlier recording technologies (“MIDI,” n.d.).

A little more than a decade later, Digital Audio Workstations (DAWs) enabled the recording, manipulation, and editing of both MIDI and audio data on personal computers, thus opening new possibilities for music production and composition. These capabilities were further enhanced by the introduction of plug-ins — self-contained audio generation or processing software modules — which could be integrated into the DAW to expand its resources and functionalities (Manning 2013).

This potential was again expanded by the use of laptop computers in dedicated laptop orchestras, which emerged in the early 2000s. Enabled by networked audio technologies and

programming languages such as Supercollider and Max/MSP, orchestra members were able to transmit audio in real time and design their own instruments specifically for a particular piece or ensemble configuration. These novel possibilities also raised new challenges and questions. For instance, how much interaction should occur between the performer and the laptop, and how much should be left to automation or algorithms? Additionally, how complex can a single sound source be when multiple players are performing simultaneously? These questions remain topics of ongoing debate and present significant challenges. Nonetheless, such experiments have proven to be fertile ground for community-based electronic music-making endeavors, which contrasts with the traditionally isolated, studio-based production methods of electronic music (Trueman 2007).

With the steady advancement of technology — most recently exemplified by AI-generated audio — electronic music continues to evolve and expand. Despite the genre's diversity and fluidity, certain key narratives can be identified. One of these is synthesis, a technique used to construct sonic material and generate entirely novel sounds. This will be the next area of focus before examining the unique characteristics of improvisation in electronic music.

3.3 Synthesis and Synthesizers

A recurring motif throughout the history of electronic music is the concept and technique of synthesis, closely tied to the use of the synthesizer. In the following sections, the essential methods of synthesis and the fundamental components of synthesizers will be outlined. This examination is crucial not only for understanding how most sounds in electronic music are created and what their defining characteristics are, but also for exploring how synthesizer players engage with the machine in different ways.

The primary concept behind synthesis is the combination of individual components to form a new, unified whole. This process can be applied in various fields, including video synthesis, speech synthesis in telecommunications, and sound synthesis. Despite the diversity of applications, all synthesizers share two central components: an interface that allows the user to control the apparatus, and an engine that performs the synthesis by processing the control inputs and generating an output based on them. In sound synthesis, there are two primary categories of machines used to generate sound: performance synthesizers and modular synthesizers. The former is designed as a complete unit, with all the necessary components for sound production already included and interconnected, allowing for

immediate use. In contrast, modular synthesizers offer greater flexibility, as they can be assembled according to the individual preferences of the synthesist, allowing for highly customized configurations and sound possibilities (Russ 2009).

The main components of a sound synthesizer — found in both modular and performance synthesizers — include oscillators, filters, envelope generators, modulation sources, control sources, and effects.

Oscillators form the foundational building blocks for sound production in synthesizers and can be controlled either by voltage (analog) or digitally. In their most common form — wave type oscillators — they generate up to four types of periodic waves: sine, triangle, sawtooth, and pulse (or square) waves. These waves not only vary in shape but also produce distinct sonic characteristics. Sine waves create a pure tone corresponding to the fundamental frequency with no harmonic content, resulting in a "flat" sound. Triangle waves, while still dark, are brighter than sine waves, whereas sawtooth waves, which include a full range of harmonics[2], have a much brighter and richer sound. Pulse waves, despite containing only odd harmonics, also produce a bright sound and are often used to replicate the tonal qualities of woodwind instruments (Shepard 2013).

Combining different oscillator waveforms can produce a wide range of interesting sonic textures. To further refine these timbres, audio filters are applied. Filters come in various designs and configurations. Initially constructed from basic electronic components, modern digital filters rely on complex mathematical algorithms. Despite differences in their construction, all filters operate on the same principle: they allow certain frequencies to pass through while attenuating or excluding others. The names of audio filters typically correspond to the frequency range they allow to pass. Some of the most common types include low-pass, high-pass, band-pass, and band-reject (or notch) filters. As their names imply, low-pass filters permit frequencies below a specific cutoff point to pass, while high-pass filters allow only frequencies above the cutoff point. Band-pass filters transmit frequencies between two cutoff points, whereas band-reject filters exclude frequencies within that range. These designs enable more focused and articulate sound shaping, allowing for greater precision in sound design (Shepard 2013).

Envelope generators are essential for shaping parameters like the amplitude curve of a sound or the intensity of an effect. Traditionally, they operate in four stages: attack, decay, sustain, and release, often abbreviated as ADSR. This configuration can be modified to

[2] Harmonics are the sum of tones above a (fundamental) tone where the frequency of each of the harmonic tones is an “integer (whole-number) multiple of the fundamental frequency (Shepard 2013)”.

include additional stages, such as hold, or simplified to only encompass attack and decay. The attack phase, measured in milliseconds, defines how long a sound (or event) takes to rise from zero to the desired peak level. The decay phase, also measured in milliseconds, determines the time it takes for the sound to drop to the sustain level, which is not time-based but set by the synthesizer's design. Lastly, the release phase controls how long it takes for the sound to fade to silence after the key is released on a typical keyboard synthesizer. This timing is crucial for creating natural-sounding fades and controlling how long a sound resonates (Andrea Pejrolo and Scott B. Metcalfe 2017).

To introduce animation into synthesized sounds, modulation sources are essential. These sources vary in type, but the most common are low-frequency oscillators (LFOs) and modulation envelope generators. Similar to oscillators that generate audible frequencies within the human hearing range (20 to 20,000 Hz), LFOs also produce periodic waves but operate at much lower, inaudible frequencies. These LFOs are typically used to modulate parameters of a synthesizer, such as the cutoff frequency of a lowpass filter, creating a cyclical transition between darker and brighter tones. Additionally, envelope generators can be applied not only to shape a sound's amplitude but also to modulate various parameters, enhancing the dynamic qualities of the sound (Shepard 2013).

Further complexity in sound design can be achieved by employing various effects. These range from distortion, delay-based processes, and ring modulation. Distortion occurs when a signal's amplitude exceeds its thresholds, expanding its harmonic content. Delay-based effects encompass a broad range of alterations, including echoes, reverb (which simulates different acoustic spaces), and chorus or phaser effects, which layer multiple delayed versions of a signal at short intervals to produce various sonic artifacts. Ring modulation, on the other hand, multiplies two sound sources, resulting in outputs that can range from subtle harmonic enhancements to metallic, dissonant tones (Andrea Pejrolo and Scott B. Metcalfe 2017).

A recurring question in the history of synthesizers revolves around how best to control the instrument. Traditionally, this has involved a distinction between conventional keyboard controllers and more experimental configurations like ribbon controllers or touch plates. Notable examples and the rationale behind these design choices can be seen in the work of Robert Moog and Don Buchla. While Moog also developed ribbon controllers for his synthesizers, his instruments became widely known for their keyboard interfaces. Moog explained this choice as part of his goal to provide firstly tools for musicians. In contrast, Don Buchla, an experimental musician himself, was more focused on creating unique instruments

that transcended conventional musical criteria, such as scales and standard tuning associated with Western keyboards. As a result, Buchla developed several versions of touch plate controllers and modules like the "source of uncertainty," the latter generating random voltages to control the instrument, encouraging more unconventional performance methods (Pinch and Trocco 1998). These trends extend into the realm of visual controllers, which enable synthesizers to be manipulated by light beams or gestures in front of cameras. Another category of controllers includes tactile interfaces, such as specialized gloves that transmit MIDI information to software synthesizers (Manning 2013).

Introducing these new modes of interaction also expands the possibilities for musicians in improvisational settings. This, along with how other distinct technical and conceptual factors influence improvisation within the realm of electronic music, will be the next focus of this chapter.

3.4 Aspects of Improvisation in Electronic Music

Now that a broad overview of electronic music, along with its foundational technologies and concepts, has been established, it is time to take a closer look at how improvisation manifests and is executed within the genre. This will be done by addressing key aspects, including the unique possibilities and challenges associated with interactions involving electronic instruments in the context of electronic music improvisation. Additionally, it will explore the role of music robots and the computer in this context, highlighting the expanded sonic possibilities facilitated by advanced computer systems.

In a series of interviews with electronic musicians from Vienna, Ewa Mazierska identifies two contrasting tendencies in the improvisational practices of electronic music. On one hand, she highlights the potential for creative freedom, noting that many electronic musicians work in their own studios, free from time constraints. This allows for extended periods of experimentation with sounds and interactions with machines. Additionally, the minimal conventions imposed on electronic instruments — unlike traditional instruments, which are often limited by fixed techniques — provide more opportunities for unconventional approaches and improvisation. On the other hand, Mazierska points out that the lack of understandable interactions with electronic instruments, both in studio and live settings, makes it difficult for musicians to perceive what their counterparts are doing, and for the audience to clearly identify the performance as improvisational (Mazierska 2018).

This complexity of somatic presence is evident in many forms of electronic music

improvisation. The problem arises because, in most cases, bodily gestures are primarily seen as input sources rather than accompanying movements that engage the entire body. These gestures do not necessarily contribute directly to sound production or control. However, these bodily gestures represent and influence the connection between the performer and the instrument. This interaction, traditionally found in classical orchestral contexts, fosters an intimate relationship between ensemble members and between the ensemble and the audience (Bahn, Hahn, and Trueman 2001).

Another factor contributing to the disconnect in electronic music improvisation is that historically, the design of many electronic instruments has been centered around a single performer, emphasizing their complete control over the instrument. Although this has been the traditional approach, recent innovations in instrument design aim to break away from the strict human-machine interface paradigm, positioning music-making as a social and intersubjective phenomenon. This shift is also supported by the notion that gestural controls often provide a large amount of information, potentially overwhelming a single performer's capacity to manage the instrument. Distributing control among multiple players or improvisers not only enhances the intersubjectivity of electronic music improvisation but also improves interaction with the instrument itself (Lähdeoja and Oca 2021).

Transcending the concept of bodily presence and interaction as well as providing a novel form of human-machine interaction is provided by improvisations with music robots. The types of possible interaction can be categorized as follows. The most traditional form involves programming the music robot to act according to a pre-written set of rules or a fixed symbolic score. A more interactive approach involves mapping the robot's actions to the movements and gestures of a human player through technologies like computer vision and object detection, allowing for responsive interaction. These methods rely on advanced digital techniques, such as employing Music Information Retrieval (MIR). MIR includes the ability to recognize timbre, identify instruments, detect beats and tempo, and analyze melodic or harmonic structures, thus granting the music robot a level of musicianship (Sallis et al. 2017).

Improvisation with computers offers an even more advanced and specialized set of possibilities. A key feature is the computer's ability to generate multiple events in response to a single input gesture. This capability ranges from sending various control messages to other performers or computer-operated instruments to producing several simultaneous layers of sound. By combining this ability to create complex sonic outputs with generative algorithms and Music Information Retrieval (MIR), as previously discussed, the computer can also function as an improvising musical partner. In this role, it can not only accompany human

musicians but also enhance their capabilities by making statistically informed or novel decisions, and thereby expanding the scope of real-time interaction in a musical context. (Dean 2011).

This notion of immediacy is where the computer demonstrates its strengths as a musical instrument. Unlike traditional instruments, such as the piano — where each key corresponds to a fixed musical note — the computer's interface can adapt to specific contexts and can be customized to meet the performer's individual needs. This flexibility enables non-traditional modes of operation and interaction that extend beyond the capabilities of hardware synthesizers in improvisatory contexts. Moreover, the computer's ability to perform real-time synthesis, without relying on pre-recorded material, facilitates the creation of adaptive and complex systems that challenge conventional aesthetic norms. These systems can even surpass the performer's ability to control every element, thereby introducing new ways of conceptualizing the performer's role and the relationship between human and machine in musical expression (Paine 2011).

The real-time synthesis in these complex digital systems involves innovative techniques that are uniquely enabled by digital technology, such as wavetable synthesis, additive synthesis, FM synthesis, and granular synthesis. Wavetable synthesis generates waveforms by calculating them once and storing them in a table for later use, with interpolation ensuring smooth transitions between points. However, limitations in sonic diversity led to the utilization of additive synthesis, which employs banks of sine wave oscillators where each frequency and amplitude can be independently controlled, allowing for a wide range of sounds. FM (Frequency Modulation) synthesis, introduced in the 1960s, produces distinctive sounds by modulating the frequency of one oscillator with another. Granular synthesis, which manipulates the spectral content by dividing the time domain into small intervals of sampled spectra, results in equally unique auditory effects. These techniques, implemented in programming environments like Max/MSP and Csound, provide electronic music improvisers with new sonic possibilities to be displayed in interaction via an equally novel system (Manning 2011).

The following section of this chapter will explore how these new forms of interaction and diverse synthesis techniques manifest in improvisational performances, highlighting how they differ from traditional acoustic improvisations.

Chapter 4 — A Comparative Analysis of Improvisation in Electronic and Acoustic Music

4.1 Overview

To broaden the perspective on improvisation in electronic music, highlight its unique sonic characteristics, and strengthen the connection of this work to the field of digital humanities, several quantitative audio analyses are conducted on two representative improvisation audio files — one from the acoustic music domain and the other from the electronic music domain. The initial set of analyses focuses on the rhythmic aspects, including the detection of tempo, beats, and onsets. Subsequent analyses examine the frequency spectrum to explore timbral differences between the two genres, utilizing spectral analysis visualized as spectrograms, as well as visualizations of Mel-frequency Cepstral Coefficients (MFCC) and the spectral centroid. Additionally, pitch classes are visualized through chroma feature extraction. The final analysis addresses the dynamic range, specifically analyzing the perceived loudness of the audio files.

The Python library Librosa offers a wide array of tools for conducting quantitative audio analyses. These include functions for extracting various features from audio material, such as tempo, beat tracking, and onset detection. Additionally, Librosa provides utilities for calculating essential parameters for loudness measurements, such as Root Mean Square (RMS) energy, and for generating spectrograms to visualize frequency content over time. (McFee et al. 2024).

The analyses focus on the first three minutes of Keith Jarrett's *Köln Concert* and an equivalent excerpt from Autechre's *NTS Sessions*. The selected excerpt length reflects the scope and intention of this study. Rather than aiming for a large-scale audio analysis, the objective is to provide a foundational component for the final application that serves as the centerpiece of this project. Nevertheless, the two excerpts effectively illustrate the wide range of playing techniques present in each piece.

Moreover, these two pieces were selected as they represent two extremes in improvisational approaches. Jarrett's Köln Concert is a live recording of an entirely improvised piano performance, spanning over an hour. Played on a slightly out-of-tune grand piano, this concert marks a significant turning point in his career, as it was the first of many such freely improvised solo piano concerts. Additionally, it introduced Jarrett to a wider

audience, as The Köln Concert became the best-selling solo piano album of all time (Fordham 2011).

In contrast, Autechre's *NTS Sessions* consist of a collage of improvised laptop performances by the electronic music duo. Commissioned by the London-based radio station NTS, these sessions showcase material created using the duo's signature production system, built with the visual programming language Max/MSP. The eight-hour work spans a wide array of sonic explorations, ranging from ambient soundscapes to rhythmically intense, beat-driven sections (Nosnitsky, n.d.)

The script, written in a Jupyter Notebook, is divided into two main sections. The first section involves importing all the necessary libraries, reading in the audio files, and using Librosa's native functions to extract or calculate various parameters required for visualization. These include tempo, onset detection, and spectral features. The second section focuses on visualizing the data, such as waveforms, onset detections, spectrograms, chroma features, Mel-frequency Cepstral Coefficients (MFCCs), spectral centroids, and RMS energy levels. The Jupyter Notebook is stored in a public GitHub repository, though the audio files are not included to avoid copyright issues and because their .wav format makes them too large to upload (michaelxstark [2024] 2024).

4.2 Waveform Comparison

A straightforward comparison can be made by contrasting the waveforms of the two audio files.

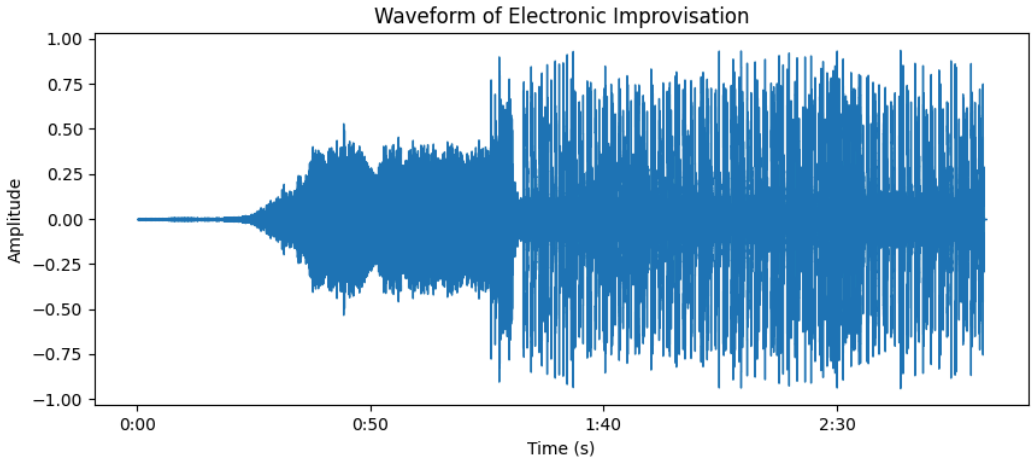

Fig. I: Waveform of Autechre - NTS Session I (00:00 - 03:00)

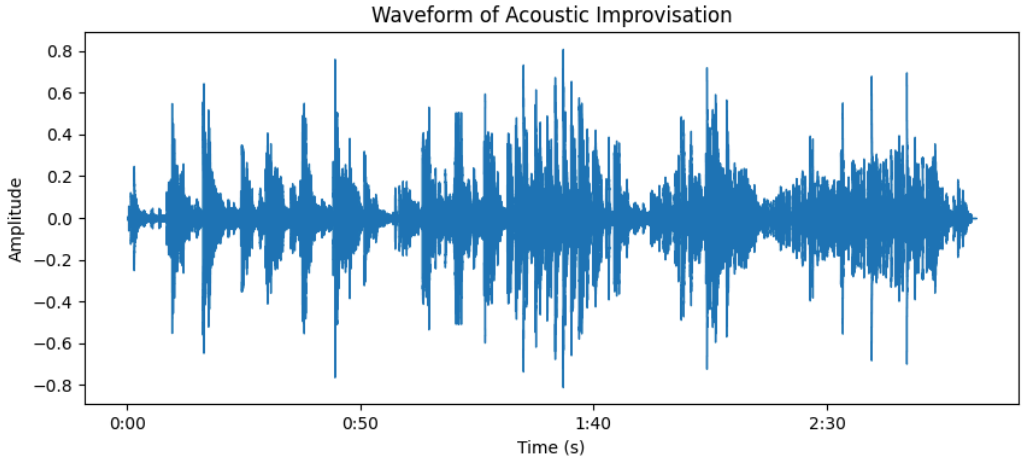

Fig. II: Waveform of Keith Jarrett - The Köln Concert (00:00 - 03:00)

The waveform of the electronic improvisation begins from silence and gradually increases in amplitude, culminating in a consistent flow of rhythmic peaks that reflect uniform onsets and intensity. In contrast, the waveform of the acoustic improvisation exhibits more pronounced dynamic variations over shorter periods, reflecting the natural ebb and flow of human performance.

4.3 Onset Detection

A more detailed representation of rhythmic consistency and development can be found through onset detections. Musical onsets represent peak positions in the onset strength curve, which indicate the start of significant audio events, such as notes or beats (McFee et al. 2015).

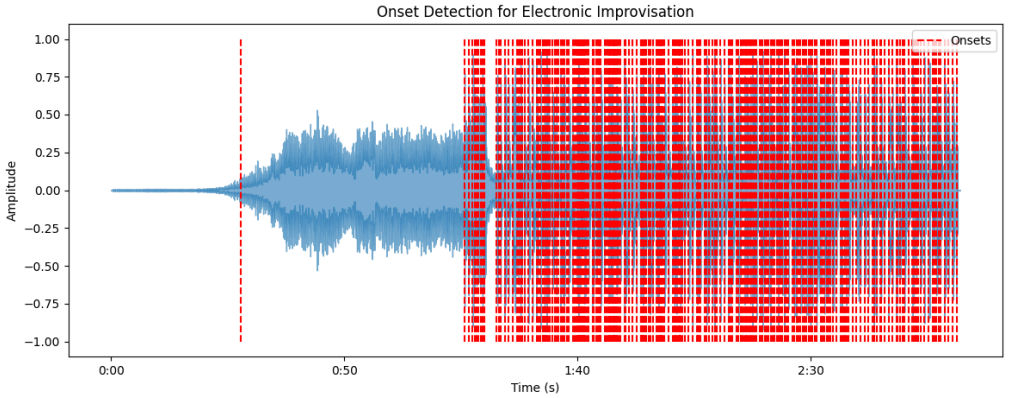

Fig. III: Onset Detection for Autechre - NTS Session I (00:00 - 03:00)

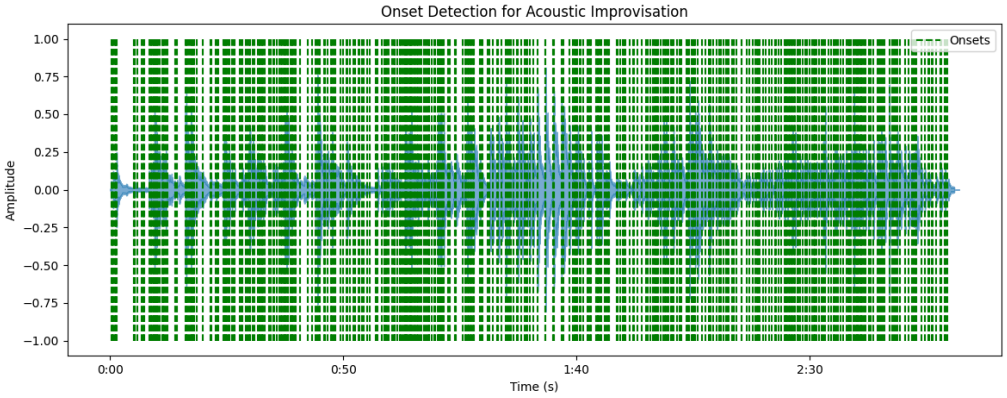

Fig. IV: Onset Detection for Keith Jarrett - The Köln Concert (00:00 - 03:00)

The comparison of the waveforms allowed for an initial estimation of the rhythmic characteristics of the two pieces, and the onset detection further clarifies these observations. Keith Jarrett begins his improvisation — which has an average tempo of 96 beats per minute — with loose yet distinct rhythmic motifs, establishing a clear rhythmic foundation from the outset. In contrast, Autechre's piece does not generate any onsets for over a minute, reflecting a more abstract and exploratory approach to rhythm. Following this initial period, the piece introduces periodic onsets at a tempo of 70 beats per minute that are commonly found in beat-driven electronic music.

4.4 Spectrograms

Moving beyond rhythmic structures, a significant difference to be anticipated lies in the distribution of frequency content, which can be attributed to the equipment utilized in the production of each piece. This distinction is clearly illustrated in the corresponding spectrograms, where variations in frequency distribution are evident.

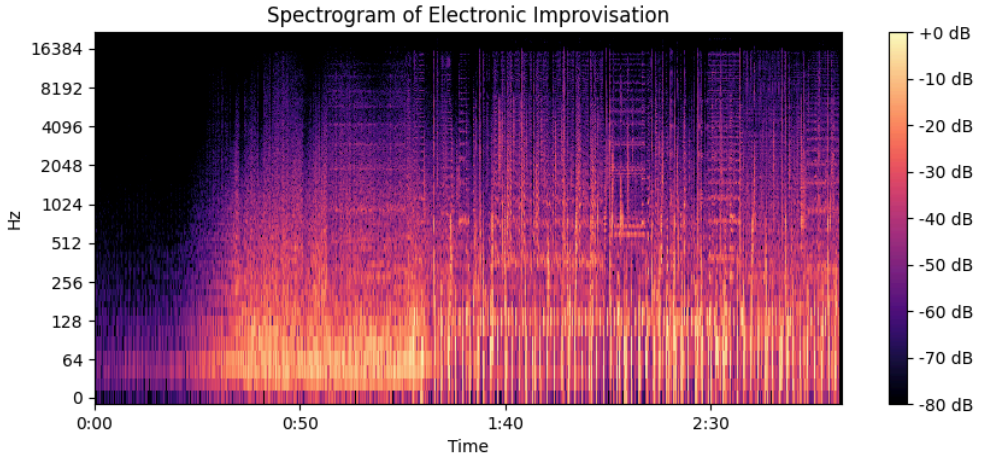

Fig. V: Spectrogram of Autechre - NTS Session I (00:00 - 03:00)

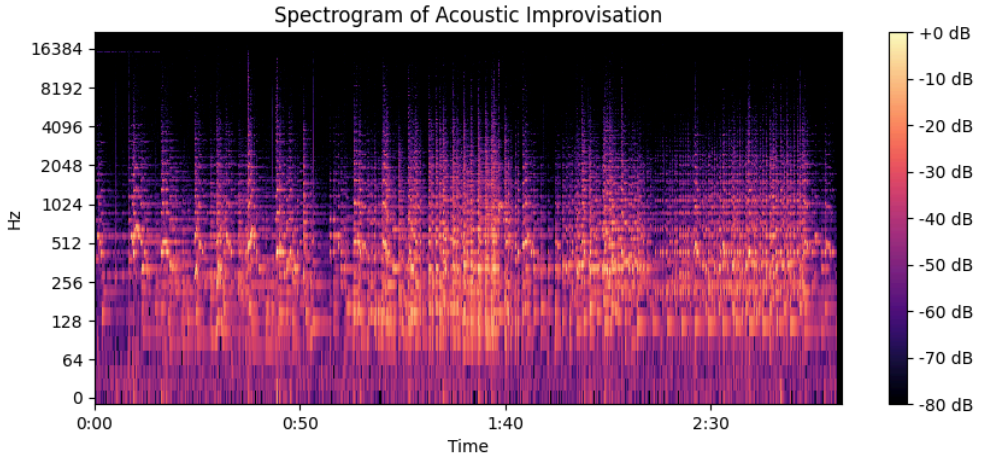

Fig. VI: Spectrogram of Keith Jarrett - The Köln Concert (00:00 - 03:00)

The spectrogram of the electronic improvisation clearly illustrates the extensive frequency range covered by the synthesized sounds predominant in Autechre's performance. It begins in the low register, with a strong emphasis on frequencies below 60 Hertz, and evolves into a palette that nearly extends to the upper limits of human hearing. Although significant content is present above 2000 Hertz, the primary emphasis remains in the range below 500 Hertz. In contrast, the piano recording from Keith Jarrett's Köln Concert does not exhibit a similarly expansive frequency range. While it does contain frequencies below 100 Hertz, these show low energy. The majority of energy is concentrated around 120 to 400 Hertz, without extending beyond 8000 Hertz. The content in the upper register may also be attributed to the recording medium used during the concert.

4.5 Chroma Feature

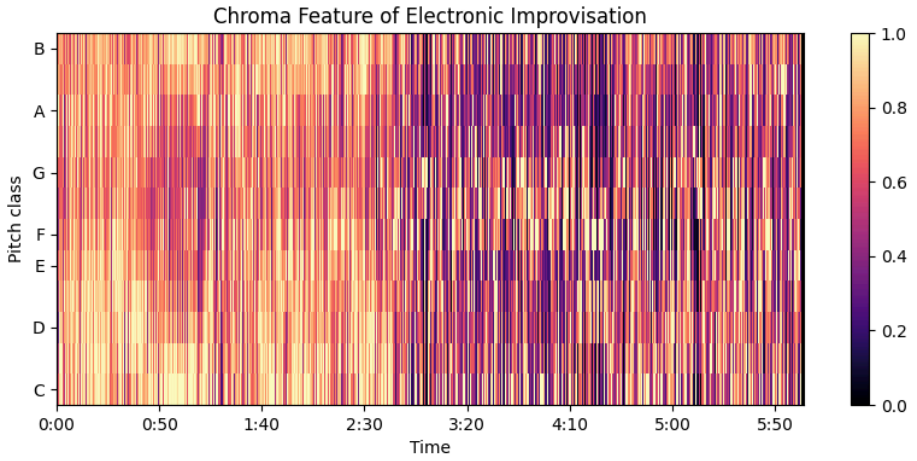

Fig. VII: Chroma Feature of Autechre - NTS Session I (00:00 - 03:00)

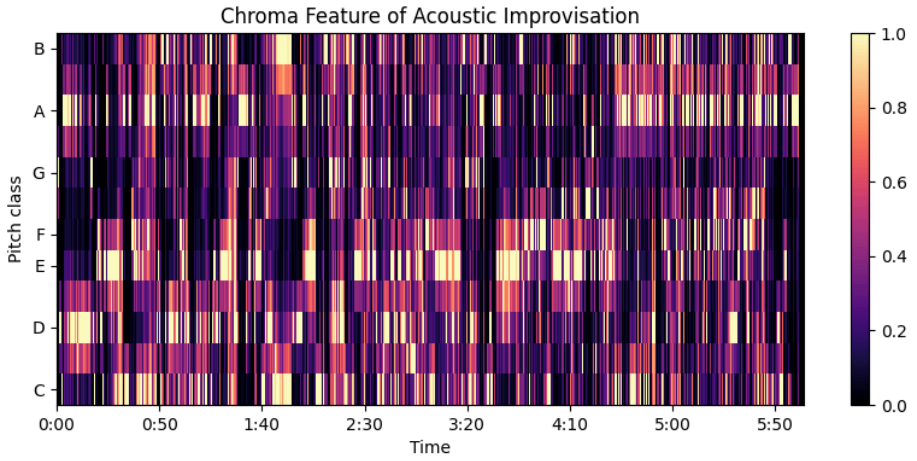

Fig. VIII: Chroma Feature of Keith Jarrett - The Köln Concert (00:00 - 03:00)

Chroma refers to classes of pitch that disregard octave range, sonic quality, and amplitude intensity. Therefore, chroma features serve as effective reference points for extracting harmonic content in musical analysis (McFee et al. 2015).

As indicated by the visualization above, Keith Jarrett's performance presents a more distinct distribution of pitches compared to Autechre's NTS Sessions. A close examination reveals that the audio snippet from *The Köln Concert* is predominantly in the key of C major, as evidenced by the strongest energy being concentrated among the notes of the scale (C, D, E, F, G, A, B). In contrast, the electronic piece demonstrates a lack of defined harmonic content, resulting in a diffuse distribution of pitch classes, with nearly equal energy across each chroma.

4.6 MFCCs

More detailed information about the timbre of a performance can be obtained through the use of Mel-frequency Cepstral Coefficients (MFCCs). This process involves compressing “the overall spectrum into a smaller number of coefficients that, when taken together, describe the general contour of the spectrum (“Learn FluCoMa,” n.d.)“.

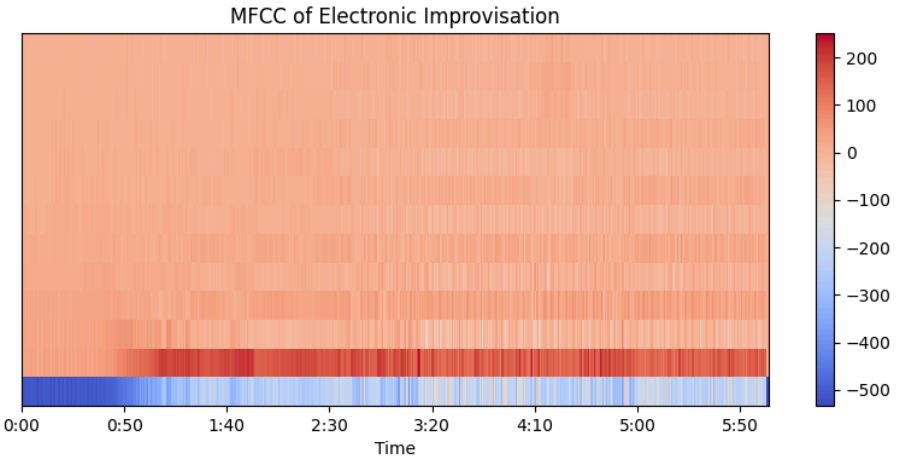

Fig. IX: MFCC of Autechre - NTS Session I (00:00 - 03:00)

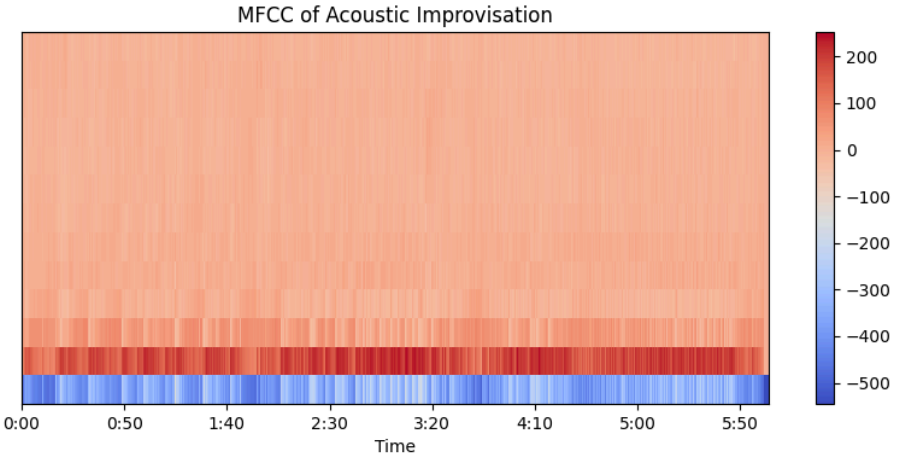

Fig. X: MFCC of Keith Jarrett - The Köln Concert (00:00 - 03:00)

Although Mel-frequency Cepstral Coefficients (MFCCs) do not directly correspond to specific frequencies, the strong energy — represented as red sections in the visualization — in the lower register indicates a consistency and stable structure in the acoustic improvisation. In contrast, the visualization of the electronic improvisation reveals a notable absence of low frequencies until just over a minute into the audio file. After this point, the energy across all coefficients begins to vary in intensity periodically, reflecting the complex timbres present in

the rhythms produced by Autechre's digital system.

4.7 Spectral Centroid

Another analytical method used for recognizing timbre is the calculation of the spectral centroid. This measure "reflects the feature of sound energy distribution (Xu et al. 2020)" and is frequently employed in acoustic research to assess the perception of sound in terms of its brightness and timbre (Xu et al. 2020). Higher values for the spectral centroid often indicate brighter or sharper sounds, while lower values suggest darker or more muted tones.

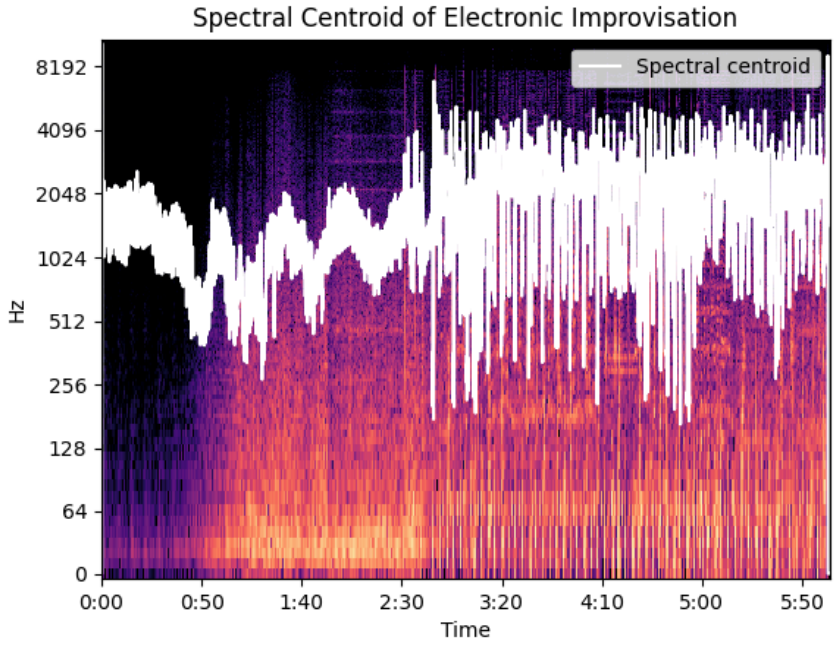

Fig. XI: Spectral Centroid of Autechre - NTS Session I (00:00 - 03:00)

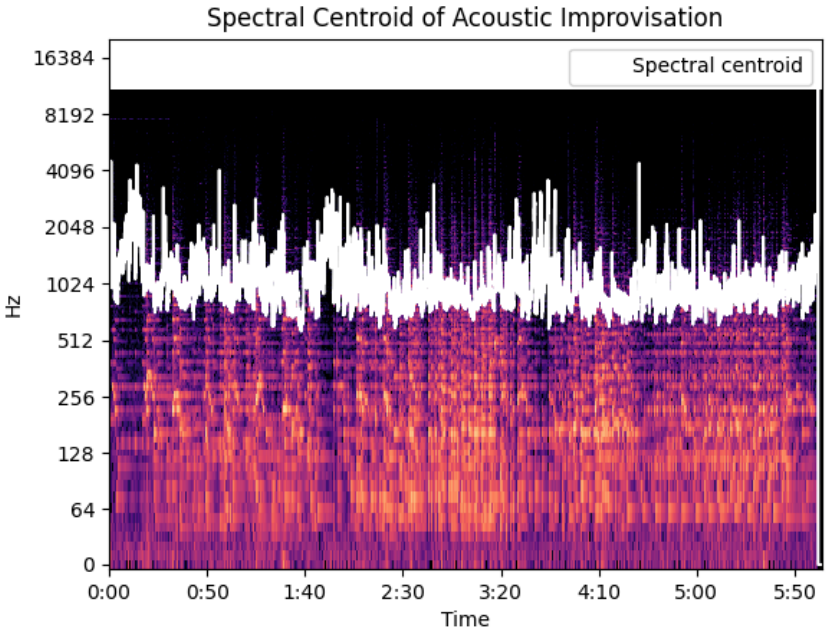

Fig. XII: Spectral Centroid of Keith Jarrett - The Köln Concert (00:00 - 03:00)

Once again, the visualization of the spectral centroid — supported by the spectrogram of the corresponding audio file — reinforces the observations regarding the differences in the improvised performances by Autechre and Keith Jarrett. In the piano performance, the timbre is modulated consistently, as indicated by the spectral centroid shifting between approximately 1000 Hz and just over 4000 Hz. In contrast, the spectral centroid calculated for the electronic improvisation initially progresses slowly, fluctuating between nearly 250 and 2000 Hz, before abruptly increasing in both variation and intensity, jumping from under 256 Hz to peaks exceeding 8000 Hz. These rapid changes reflect the significant shifts in timbre present in Autechre's opening track from the NTS Sessions.

4.8 RMS Energy

The final comparison that is conducted concerns the root-mean-square (RMS) energy that is in close conjunction to the perceived loudness of a track (Hove et al. 2019).

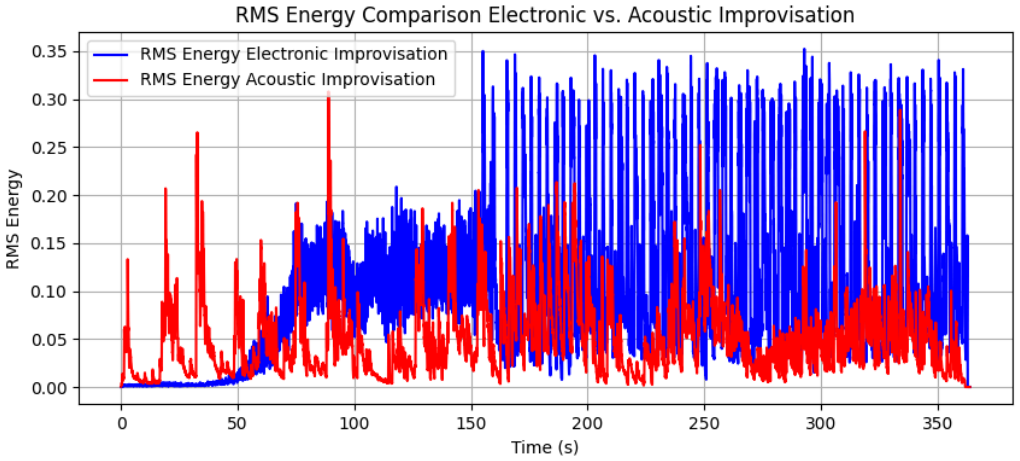

Fig. XIII: Comparison of RMS energy of Keith Jarrett - The Köln Concert (00:00 - 03:00) and Autechre - NTS Session I (00:00 - 03:00)

This comparison also highlights the fundamental differences between the recordings. Jarrett's performance demonstrates the wide dynamic range characteristic of human piano playing, with noticeable fluctuations in loudness. In contrast, Autechre's performance culminates in a highly compressed and percussive section, generating constant peaks in RMS energy and perceived loudness, which is typical of the genre.

4.9 Conclusion

Through an in-depth exploration of electronic music — its fundamental concepts, techniques, and the role of improvisation — alongside a quantitative comparison of improvised performances in electronic and acoustic contexts, the groundwork for an informative and interactive online platform for electronic music improvisation is established. The subsequent chapters will focus on the platform's design, construction, and refinement. The goal is to develop an application that integrates the distinctive features of electronic music improvisation, such as timbral complexity, innovative methods of interacting with instruments, and the ability to transcend traditional musical conventions. Additionally, the application will offer both points for cognitive reflection on these topics and the ability for immediate execution via an accompanying online instrument.

Chapter 5 — Building the Platform

5.1 Thoughts on Building Things in the Digital Humanities

Now that the fundamental resources have been covered, it is time to address the core of this project: the development and implementation of the web platform that serves as both a space for in-depth reflection on improvisation in electronic music and a digital instrument enabling users to immediately apply their ideas. In this context, the process of building — encompassing both design and coding — plays a central role.

Before delving into the technical aspects, it is essential to examine why the act of building is a crucial component of a digital humanities project such as this. Additionally, it is important to define how this endeavor should be structured to meet the standards of a scholarly project within this specialized field.

In his essay *On Building*, Stephen Ramsay explicitly — often in a provocative manner — emphasizes that the act of making and developing is a formative aspect of the Digital Humanities (DH). He argues that this is because the actual construction of a Geographic Information System (GIS) or the process of writing markup for a text provides researchers with fundamentally different insights and experiences than merely theorizing about these practices (Ramsay 2023).

This, of course, does not imply that building is the sole focus of a Digital Humanities (DH) project. Rather, it necessitates a balanced interplay between the construction process and the ability to interpret the newly generated knowledge that emerges from it (Liu 2013).

A phrase that has gained notable traction in this context is "more hack, less yack." Originating from an "un-conference" called THATCamp — which brought together scholars from the humanities and technology without pre-planned presentations or a fixed schedule — it served as a slogan encapsulating the event's core ethos. This ethos promoted a non-hierarchical and more immediate approach to academic exchange, in contrast to the formalized and traditional structures of conventional scholarly conferences. It is important to note, however, that after its initial use at THATCamp, the slogan has been interpreted in various ways that diverge from its original intent. In the context of this thesis, however, it serves as a guiding principle, underscoring the importance of immediacy and accessibility in Digital Humanities research (Nowviskie 2016).

Another perspective that seeks to reconcile the seemingly opposing fields of making and theorizing is presented by Galey and Ruecker (2010). In their essay *How a Prototype*

Argues, the authors draw a parallel between the process of editing a book and the creation of a digital prototype. They argue that just as the act of editing a book provides valuable insights into the theoretical principles of textual scholarship, the development of a digital prototype similarly contributes to the understanding of interface design. This suggests that the process of making is inherently tied to the generation of new knowledge, as the resulting product inevitably offers fresh insights into its respective field (Galey and Ruecker 2010).

Further reflections on the role of digital artifacts in academia and their relationship to theory are examined by Ramsay and Rockwell (2012). The authors initiate the discussion by posing the question of whether the act of constructing tools to facilitate scholarship constitutes scholarship in its own right. For this purpose Ramsay and Rockwell draw from several perspectives offered by fellow scholars. These range from the question whether objects can convey inherent knowledge without requiring additional commentary to the statement that the building of these tools may be able to shift the linguistic bias of the humanities. Advancing further in their analysis, the authors also bring up the point that digital tools used in the humanities are never about themselves but much more a tool at hand. Therefore they fulfill the same purpose as a theory, namely letting us think differently about the world. Finally — after having discussed the role of writing as a vehicle for scholarship — they come to the agreement that "if the quality of the interventions that occur as a result of building are as interesting as those that are typically established through writing, then that activity is, for all intents and purposes, scholarship (Ramsay and Rockwell 2012, 83)".

Building on these ideas, the design of the platform is now taking shape. One key aspect is its potential to shift the linguistic bias of the humanities. By offering users a digital instrument to engage in improvisational practices in real time, the platform introduces an intuitive, haptic element to scholarly reflection on the subject. Additionally, the impulse statements, derived from the literature review, will serve as a bridge between the act of building and the process of theorizing.

5.2 Core Components of the Platform

5.2.1 Oblique Strategies

One core component of the application, as discussed above, is the concept of "impulse statements." These brief sentences serve as starting points for creative engagement with various aspects of musical improvisation. The aim is to distill the insights gained from the literature review into thought-provoking prompts. A key inspiration for this approach is

Oblique Strategies, a set of creative prompts developed by composer, artist, and producer Brian Eno in collaboration with painter Peter Schmidt (Eno and Schmidt 2015). To establish a solid foundation for the development of impulse statements in this project, the following section will examine the origins and underlying principles of *Oblique Strategies*.

These strategies consist of a set of more than 100 cards, originally created by Eno and Schmidt in 1975 as a tool for overcoming creative blocks (Albiez and Pattie 2016). Beyond that, they have also been used to navigate stressful situations in recording studios (Wurgaft 2017) and as coordinating devices for collaborative artistic endeavors (Albiez and Pattie 2016).

The *"over one hundred worthwhile dilemmas,"* as the subtitle suggests, are loosely inspired by the ancient Chinese philosophical text *I Ching*. The oracle-like nature of this *Book of Changes* not only influenced the compositions of John Cage but also served as the stylistic foundation for Eno and Schmidt's creation. For Eno, the idea of using aphorisms originated early in his career when he employed them during the production of artworks and in the studio with his band, Roxy Music. Similarly, Peter Schmidt was drawn to the practice of recording inspirational sentences closely tied to his artistic process. When the two friends compared their aphoristic notes, they discovered significant overlap, which ultimately led them to publish the first iteration of *Oblique Strategies* in 1975 (Tamm, n.d.).

Apart from creating the *Oblique Strategies*, Brian Eno also incorporated them into his own work. Their first documented use is credited on the album *Another Green World*, where Eno entered the recording studio without any pre-written material. By doing so, he sought to avoid limiting himself in his exploration of the studio's sonic possibilities while still allowing the *Oblique Strategies* to guide his creative decisions. Additionally, unlike his previous albums, Eno recorded most of the material himself. When he did invite guest musicians, he instructed them only to produce loops, which he later integrated into his compositions (Albiez and Pattie 2016).

Another notable use of the *Oblique Strategies* can be found in the creation of David Bowie's song *Sense of Doubt*, on which Brian Eno also collaborated. During the production process, both Eno and Bowie drew cards from the deck and attempted to adhere as closely as possible to the instructions provided. However, in this particular instance, the cards they selected conveyed opposing directives. While Eno's card advised him to identify as many similarities as possible, Bowie's card instructed him to emphasize differences (Tamm, n.d.).

As demonstrated in the previous example, the *Oblique Strategies* are intentionally cryptic, a characteristic designed to evoke a wide range of associations and actions. While

they draw inspiration from the *I Ching*, as previously mentioned, they do not require users to interpret them in a spiritual manner. Rather, Eno and Schmidt aimed to create simple yet expressive prompts for creative endeavors, encouraging non-linear approaches to artistic production (Tamm, n.d.).

The prompts encompass a wide range of semantic content. Some are directly related to musical concepts, such as *"Imagine the music as a moving chain or caterpillar," "Is the tuning intonation correct?"* or *"Listen in total darkness, or in a very large room, very quietly."* Others offer broader artistic guidance, including *"Make a blank valuable by putting it in an exquisite frame," "Use an unacceptable color,"* or *"Use something nearby as a model."* Additionally, the *Oblique Strategies* venture into the absurd with statements like *"Call your mother and ask her what to do," "Krawall!"* and *"Tape your mouth."* (Eno and Schmidt 2015).

With these conceptual ideas and the distinctive tone and structure of Eno's and Schmidt's creations in mind, the following section will document and explain the development of the impulse statements for the web application. As discussed earlier, the content for this work will be derived from the literature research conducted in the first two chapters. The topics will encompass historical practices of improvisation, observations on cognitive processes during improvisational activities, and aspects specifically inherent to the practice within the electronic music domain.

5.2.2 Constructing the impulse statements

An examination of the Oblique Strategies prompts reveals that they are characterized by their brevity. However, this project will not adopt such a strict reduction. Instead, the focus will be on maintaining their open-ended nature while allowing for a more expansive formulation. The initial set of prompts for the web application will consist of 25 entries, each derived from key insights gained through the literature research. In the following section, each prompt will be presented as a headline, accompanied by the corresponding research reference to establish its scholarly foundation.

Choose a musical style. Improvise. Change the style. Improvise again. What shifts? Now omit the style completely. What changes now?

Derek Bailey distinguishes between idiomatic and non-idiomatic improvisation. This prompt encourages performers to explore the defining elements of a given genre — such as tempo, melody, and rhythm — while also reflecting on how improvisation changes when freed from

stylistic constraints, as practiced by Bailey himself (Derek Bailey 1980).

Establish a motif. Alter the tempo. What remains? What transforms?
This prompt references the medieval improvisational practice of allowing performers to determine the tempo of a piece (Bechtel 1980). Additionally, it challenges the boundary between composition and improvisation by requiring the performer to repeat an improvised motif while modifying only one parameter, prompting deeper reflection on structural and expressive change.

Find a second player. Improvise until you discover a motif you like. Now establish an accompanying melody. How do you approach it?
This prompt draws inspiration from early polyphonic practices, particularly the ways in which harmonic material was generated (Moelants 2014). It also encourages performers to explore different strategies for creating harmonies. Do they prioritize melodic contour, rely on underlying harmonic progressions, or follow an intuitive, ear-driven approach? By examining these different methods, performers gain insight into their own harmonic decision-making processes.

Find a second player. Study counterpoint. Improvise until you establish a motif. Now create an accompanying line that reflects your understanding of counterpoint.
The development of counterpoint marked a significant transformation in Baroque composition and improvisation, introducing greater independence between voices compared to the earlier, more rigidly structured polyphony. Unlike earlier harmonic practices, in which secondary voices were strictly dependent on a leading melody, counterpoint allows each voice to maintain its own distinct motion (Mulligan 2024). This prompt challenges performers to experiment with their interpretation of independence and interplay when constructing an accompanying line in real time.

Study the different parts of the sonata form. Now improvise and try to structure your improvisation accordingly.
In the late 18th and early 19th centuries, improvisation was often structured within established musical forms, such as the sonata. This prompt guides players toward shaping their improvisations in a similar way, experiencing the formal and developmental aspects of classical improvisation (Eggers and Lehner 2021).

Find several players. Establish a rhythmic foundation. Now one of the players starts developing a motif while the others improvise accompanying material. Is there chaos? How do you deal with it?

For much of Western music history, improvisation in polyphonic settings was typically limited to a single voice. The rise of jazz marked a significant shift, allowing multiple improvising voices to coexist (Benson 2006). This prompt lets players explore the concept of heterophony, challenging them to navigate the balance between structure and freedom in collective improvisation.

Sit still. Take a deep breath. Now freely improvise for one minute. Where did you start? How did you end?

The free improvisation movement that emerged in the 1950s and 1960s embraced a radically open approach by rejecting conventional frameworks such as jazz standards, rhythmic structures, and melody. Inspired in part by John Cage's engagement with Zen Buddhism, musicians sought to challenge established notions of music-making (Sansom 2001). This prompt encourages players to engage with free improvisation and reflect on the challenges that arise when creating without predetermined structures.

Make the instrument sound like it has never sounded before. How did you achieve it? Can you do it again?

A defining characteristic of improvisation in the noise music genre is the unconventional use of instruments. This can involve exploring new playing techniques or manipulating an instrument's settings in unintended ways (Igarashi 1997). This prompt invites players to expand their sonic palette, encouraging them to reconsider both the limitations and possibilities of their instrument in order to generate novel material for improvisation.

Find a group of players. Now improvise freely together for five minutes. What dynamics can you observe? Who is leading? Is there equality?

Beyond the musical elements of improvisatory practices, the groups involved in free improvisation also examined the social dynamics at play during group performances. Reflecting the concepts inherent in David Toop's (Toop, David 2008) work on this subject, this prompt encourages participants to develop an awareness of the underlying power dynamics within musical group improvisations.

Improvise with another player. Be aware of what they play. At one point, imitate their

playing. How did they react?

Active listening is a fundamental skill for effective musical improvisation, as highlighted by Cobussen in his analysis of *The Baltic Suite* (Cobussen 2017). This prompt encourages players to engage in a mindful and attentive state of listening while performing, helping them refine their decision-making processes during improvisation.

Improvise with a group of players. Listen closely. Do you speak the same language?

Cobussen also identifies the ability to adapt to a group's musical language as a key skill in improvisation. This refers to a shared understanding of melodic, rhythmic, and stylistic elements among the performers (Cobussen 2017). The prompt above encourages players to listen attentively while also reflecting on their own musical choices within the improvisational context.

Improvise freely for a minute. Reflect on what you have just played. Does it relate to the zeitgeist? And if so, how?

Daikoku's study highlights how musical improvisation is deeply influenced by the evolving genres and stylistic tendencies of different eras throughout the 20th and 21st centuries (Daikoku 2024). This prompt encourages players to reflect on their own improvisational choices and consider how their musical expression is shaped by contemporary practices.

Improvise in different settings. Reflect on the conditions. When was it effortless? When was it challenging? Can you identify why?

The concept of *flow state* is particularly relevant to musical improvisation. It describes the experience of simultaneous maximum control and minimal effort when navigating complex decision-making processes, such as those inherent to improvisation (Landau and Limb 2017). This prompt encourages players to reflect on the conditions that facilitate or hinder this mental state, helping them identify factors that contribute to an optimal improvisational experience.

Make a recording of your improvisation. Listen to it. What did you enjoy more — the process or the product?

The dichotomy between composition and improvisation is central to defining the field and carries aesthetic implications. In his observations, Hamilton differentiates between an aesthetic of perfection (associated with composition) and imperfection (linked to improvisation), while also highlighting other binary oppositions, such as product versus process (Hamilton 2000). This prompt encourages players to reflect on this distinction and

examine their own relationship to improvisation in relation to these concepts.

Improvise for a minute. Avoid tonal sounds. Is there still music?
In the early 20th century, the Futurists found conventional music notation and established playing techniques restrictive. Fueled by their fascination with technological innovation, they designed machines to integrate noise into their sound practices (Levi 2000). The prompt above encourages players to explore the sonic limits of their instruments and reflect on their own perception of what constitutes music.

Go to the instrument. Play a note with a basic sound. Now improvise for a minute by altering only the sonic quality — never the pitch. How do you generate variation?
Referencing Hermann von Helmholtz's *Sensations of Tone* — in which the scientist describes timbre as the interplay between a fundamental tone and its related overtones — John Cage defines the core aspects of sound as timbre, frequency, amplitude, and duration. He later expands this idea by incorporating onset and decay (Holmes 2002). The statement above encourages a deeper engagement with the tonal quality of sound during improvisation, shifting focus away from pitch and toward the nuances of sonic expression.

Find other players. Each goes to the instrument. Improvise for five minutes. Explore all the sonic possibilities of the instrument. Was there enough space for all ideas?
A central question in improvisation with electronic instruments — especially computers — is how much complexity a single instance can contribute within an ensemble setting (Trueman 2007). This prompt encourages players to explore the sonic boundaries of the instrument, reflecting on the balance between individual expression and collective cohesion. How much complexity can one generate before overwhelming the group dynamic? Where does sonic density enhance the improvisation, and where does it hinder it?

Go to the instrument. Make the delay effect audible. Now improvise for a minute and let the echoes guide you. Where did they lead you?
Time-based effects like delay offer a vast spectrum of sonic possibilities, from simple echoes to dramatic transformations of the source material through abrupt changes in delay time (Andrea Pejrolo and Scott B. Metcalfe 2017). This prompt encourages players to use the effect not merely as an embellishment but as an active agent in shaping their improvisation. By engaging deeply with the effect's response, users can explore how sound itself — not traditional musical structures — can serve as the foundation for improvisation, reinforcing a core perspective inherent to electronic music.

Improvise on different instruments. How does the interface influence your practice? What hinders? What enhances it?

A defining aspect of improvisation with electronic instruments is the variety of control interfaces available. From ribbon controllers to touch plates, electronic instruments offer unconventional modes of interaction that significantly shape musical expression (Pinch and Trocco 1998). This prompt invites users to reflect on how the physical design of an instrument influences their improvisational approach, highlighting both the limitations and possibilities that different interfaces introduce.

Go to the instrument. Improvise for a minute. Was it easy? How would you practice?

Conducting a series of interviews with electronic musicians from Vienna, Ewa Mazierska (2018) observed that the lack of standardized playing conventions in electronic instruments fosters a more open-ended approach to performance. This prompt aims at giving users the opportunity to explore the instrument freely, reflect on their initial experience, and consider how they might develop their own methods for practice and mastery.

Find one or more partners. Improvise freely for five minutes. Observe your bodies. How did they move? Did they interact? How?

Bodily gestures in electronic music improvisation — and live electronic performance in general — present a unique challenge. Unlike traditional acoustic ensembles, where physical movement is often seen as an expressive or communicative element, gestures in electronic music are frequently reduced to parameter adjustments, such as altering timbre or pitch (Bahn, Hahn, and Trueman 2001). This statement encourages users to consider their physical engagement with their instrument and to explore how movement might influence both their interaction with fellow musicians and their overall musical expression.

Go to the instrument. Explore how many sonic sensations you can produce with a single gesture. How does this compare to an acoustic instrument?

Electronic instruments—particularly computer-based systems—offer a unique mode of interaction. With the right setup, a single input gesture can trigger multiple sonic events, influencing parameters such as pitch, timbre, volume, and audio effects simultaneously (Dean 2011). The instrument used in this web application follows this principle, allowing for multidimensional control through a single movement. This prompt encourages users to explore these possibilities and reflect on how gestural control in electronic instruments differs from that of traditional acoustic instruments.

Find a partner. Go to the instrument. Divide the space — one person controls the upper half, the other the lower. Improvise for a minute. What happened?
For much of electronic music history, instruments were designed for solo performers. However, recent developments in instrument design have increasingly embraced multi-user interaction, allowing multiple performers to engage with a single system (Lähdeoja and Oca 2021). This prompt wants users to explore how improvisation changes when two players share control, highlighting the dynamics of collaboration and the evolving nature of electronic music performance.

Go to the instrument. Adjust only the FM parameter. Discover as many useful sounds as possible. Now improvise using your new repertoire.
Frequency Modulation (FM) synthesis involves one oscillator modulating the frequency of another, enabling a wide range of sonic possibilities — from subtle vibrato to metallic bell-like tones (Manning 2011). This statement invites users to explore the sonic potential of FM synthesis, refining their ability to shape sound and building a personalized repertoire for improvisation.

Listen to two improvisations — one acoustic and one electronic. Now go to the instrument and attempt to imitate both. What did you observe?
A central focus of this work is to examine how improvisational practices in electronic music differ from those in acoustic settings. As discussed in the second part of the chapter on improvisation in electronic music, these differences span various aspects, including timbral contrasts and the number of discernible tonal sounds. This prompt encourages users to explore these distinctions firsthand by attempting to recreate both types of improvisation on the instrument provided by the application.

5.2.3 The Instrument

As previously proposed in this work, the web-based application forming the practical component of this project will incorporate a digital instrument. This instrument is intended as a vehicle for executing the reflective processes prompted by the impulse statements generated earlier.

The question now arises: how should this instrument be designed? As demonstrated in various studies, including Ewa Mazierska's (2018) research on electronic musicians in Vienna, electronic instruments often feature unconventional designs and lack a standardized format. This inherently open-ended nature allows for flexibility but also necessitates careful

consideration in defining the instrument's structure.

Several guiding principles can help shape its design. The first is a practical constraint: since the application is intended for mobile devices, interaction via a touchscreen is essential. The second guiding factor stems from a recurring theme in this research — the ability of electronic instruments to produce a wide range of timbres. Therefore, the instrument must allow for a certain degree of tonal flexibility. The third consideration relates to its role in group improvisation. As noted by Trueman (Trueman 2007), an electronic instrument must carefully balance the density of sonic information it contributes within an ensemble. This principle also aligns with a technical requirement: for the instrument to function efficiently on the web without latency issues, it must remain lightweight.

Taking these factors into account — along with a historical perspective — the theremin, with added functionality to expand its timbral possibilities, will serve as the primary model for the instrument within the application.

5.2.4 Theremin +

The theremin holds particular significance for this project, not only due to its unique playing technique but also because of its historical impact on electronic music. Originally patented by its inventor, Léon Theremin, in 1928, the instrument has been shaping the sonic landscape for nearly a century (Andrea Pejrolo and Scott B. Metcalfe 2017).

The instrument's core functionality is controlled through hand gestures, allowing the player to manipulate both frequency and volume. The pitch is determined by the distance between one hand and a vertically mounted antenna, while the closeness of the other hand to a horizontally positioned antenna regulates the instrument's volume (Skeldon et al. 1998).

The sound itself is generated by "radio tubes producing oscillations at two sound-wave frequencies above the range of hearing; together, they produce a lower audible frequency equal to the difference in their rates of vibration. ("Theremin -- Britannica Academic," n.d.)". The movement of the right hand toward or away from the vertical antenna changes the pitch of one of the inaudible frequencies, causing the audible pitch to follow accordingly ("Theremin -- Britannica Academic," n.d.).

This highly physical aspect of playing the theremin makes it unique among musical instruments, as it requires no direct physical contact. Moreover, it presents an intriguing subject for exploration within the context of electronic music, where the role of the body and movement is complex — oscillating between being a mere input source and a fundamental

element of communication, as demonstrated by Bahn, Hahn, and Trueman (2001). The bodily characteristics of theremin performance and their relationship to cybernetics are examined in detail by Latham (2021). She analyzes how the theremin — and particularly its playing technique — challenges traditional notions of the connection between a sound's origin and the visual perception of performance. In doing so, the theremin becomes emblematic of cybernetic ideas, blurring the boundaries between human and machine. This was especially true at the time of its invention when the concept of machines responding directly to human movement without physical touch was radically novel (Latham 2021).

While the absence of physical interaction is crucial to understanding the theremin, projects such as Usabaev et al.'s virtual theremin have adapted this principle by using a digital device's camera to capture users' gestures, allowing them to "perform" the theremin and control pitch and volume without direct contact (Usabaev, Eschenbacher, and Brennecke 2022). However, in this project, the instrument's functionality will be adapted for a touchscreen interface. This approach allows for the integration of two additional sonic features, expanding the instrument's capacity to produce a wider range of sonic events.

5.2.5 FM Synthesis

The first enhancement to the instrument is the incorporation of frequency modulation (FM) synthesis. Originally described by John Chowning, this synthesis technique "allows the production of complex spectra with very great simplicity (Chowning 1977)". As the name suggests, FM synthesis operates by modulating the frequency of a carrier wave with a modulating wave. When applied using sine waves, the resulting signal can be mathematically expressed as:

$$y(t) = \sin(2\pi fct + I\sin(2\pi fmt))$$

where *fc* represents the frequency of the carrier oscillator, *I* denotes the modulation index (the extent to which the carrier wave is modulated), and *fm* corresponds to the frequency of the modulating wave (Caspe, McPherson, and Sandler 2022).

5.2.6 Digital Delay

One of the most powerful techniques for manipulating audio is the delay effect. This phenomenon is easily perceived in an acoustic space when a sound signal reflects off a

distant surface, creating a time-delayed replication of the original sound. In the digital domain, the ability to adjust the delay time — analogous to altering the distance of the reflecting surface in the real-world example — enables not only the standard repetition of the signal but also a range of more complex audio effects. These include pitch and timbre-altering effects such as phasers, flangers, and chorus, which modify the signal in more dramatic ways (Zölzer et al. 2002). This makes the delay effect a valuable addition to the instrument, as it significantly expands its sonic possibilities.

5.2.7 The Landing Page

The final element requiring a conceptual framework is the landing page. Given that all other sections of the application are grounded in references from music history, it seems fitting to maintain this thematic continuity throughout the entire website.

As previously discussed, John Cage is a pivotal figure in both the evolution of electronic music and the development of improvisational practices. His *Lecture on Nothing*, part of a collection of his writings and lectures titled *Silence*, presents a compelling design reference for the landing page. This is because its structure directly reflects Cage's compositional approach at the time, employing rhythmic frameworks similar to those he used in his musical works (Cage 1961).

The concept of applying musical structure to written text — further expanded through the use of chance operations — is explored in another essay from *Silence*, titled *Composition as Process*. In this piece, Cage provides insight into the construction of *Music of Changes*, a work in which he used chance operations to determine tempo shifts at specific moments. Additionally, he devised a system for subdividing sections into smaller units based on a strict numerical framework, resulting in a composition that is both highly structured and seemingly free (Cage 1961).

To emulate this approach, the landing page of the application — where introductory text and a hyperlink system to other sections will be presented — will incorporate chance operations and a non-linear text structure. This design challenges the user's assumptions about linear information presentation while also fostering an initial improvisational interaction with the material. Each time the page is loaded, a random algorithm will reorganize the text — structured into small units of short sentences — encouraging users to engage with shifting perspectives and fluid structures.

5.3 Designing the Application

To establish a clearer vision of the application's appearance and provide a structured foundation for the subsequent coding process, a design phase is conducted using the design software *Lunacy*.

Lunacy was selected for this purpose due to its accessibility as a free, cross-platform tool that operates efficiently without requiring substantial computing power. Furthermore, it incorporates industry-standard features, including AI-assisted functionalities such as text mockups. These capabilities make Lunacy a practical choice for generating preliminary visualizations of the final application (“About Lunacy,” n.d.).

5.3.1 General Design Guidelines

Several key design considerations for the application have emerged throughout this work. One foundational principle is the assumption posited by Ramsay and Rockwell (2012) that a digital tool should act similar to a theory and therefore act as a vehicle to alter our perception of the world. This perspective can be further extended by Whitelaw’s (2015) argument — though originally applied to digital art collections — that the development of *generous interfaces*, which prioritize browsing over targeted searching, can significantly enrich user experience.

Additionally, the application draws on references from the physical world, including the *Oblique Strategies* cards, the textual structure of John Cage’s *Silence*, and the theremin. These elements share a distinctly minimalist aesthetic: the *Oblique Strategies* cards are simple white pieces of cardboard with black ink and no embellishments, Cage’s structured text follows a similarly unadorned format, and the theremin features an extremely sparse interface, relying solely on the player's hand movements in relation to its sensors. Considering these influences, a minimalistic, clear and open layout design for the application is a logical and necessary direction in the forthcoming design process. Furthermore, since the instrument integrated into the web application is touch-based, the design will prioritize a mobile-first approach. Therefore, the design prototype will be developed using the iPhone SE as a reference model for demonstration purposes.

5.3.2 Designing the Landing Page

The first element in the process is the landing page, which will present the following sentences. In accordance with John Cage's considerations, these sentences will be

restructured each time the page is loaded:

a.) Welcome to *Into the Deep End*

b.) An informative, interactive online platform for improvisation in electronic music

c.) Get inspired by a prompt

d.) Bring your ideas to life using the touchscreen instrument

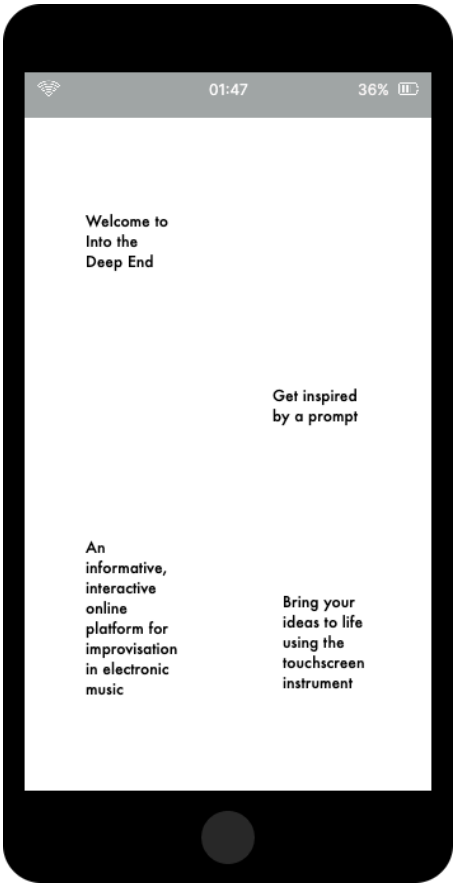

Fig. XIV: Design Prototype of the Landing Page of the application

Each sentence will serve as a hyperlink, directing users either to the prompt page or the instrument page. Additionally, the phrase “An informative, interactive online platform for improvisation in electronic music” will function as a link to an instructional page. This page will provide guidance on using the instrument, introduce its components and historical context, and offer a curated collection of resources corresponding to each prompt.

5.3.3 Designing the Impulse Statement / Prompt Page

The *Prompt Page*, which presents the impulse statements derived from the literature review and quantitative audio analyses, will be structured in three distinct stages. The first stage invites users to initiate a random selection of a prompt by tapping anywhere on the screen. The second stage serves as a transitional phase, visually indicating that the selection process is in progress. In the third and final stage, the selected prompt is displayed. To facilitate seamless navigation, a circular button positioned in the bottom left corner will allow users to return to the landing page.

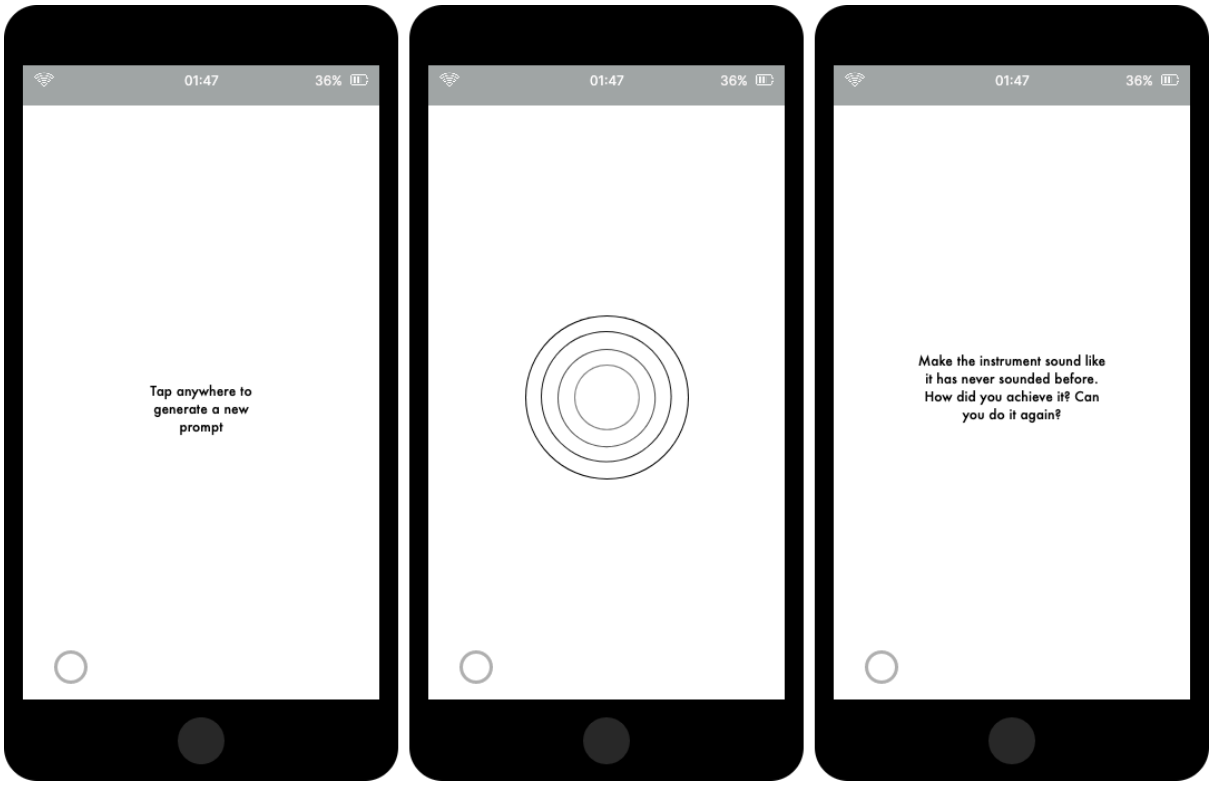

Fig. XV: Design Prototype of the Prompt Page / Impulse Statements

5.3.4 Designing the Instrument Page

The *Instrument Page* is structured into four sections, each corresponding to a key component of the tool. Given that amplitude and frequency are the primary parameters of the theremin, these controls are positioned at the bottom of the interface, side by side, to reflect the layout of the original instrument. The upper section is dedicated to the additional features: *delay* and *frequency modulation (FM)***.**

The delay and FM parameters are controlled via an XY-pad**,** enabling simultaneous

manipulation of multiple aspects — delay time and delay amount, as well as the modulation oscillator's frequency and the intensity of frequency modulation. The amplitude is adjusted using a slider, allowing for both gradual attack and decay phases as well as abrupt dynamic changes. The frequency of the primary sound generator is also controlled through an XY-style pad. To enhance playability, the frequency will be quantized to discrete steps — a concept that will be further elaborated in the technical implementation section.

Additionally, to prevent unintended interactions during performance, the home button has been repositioned to the top center of the interface, ensuring a more intuitive and uninterrupted user experience.

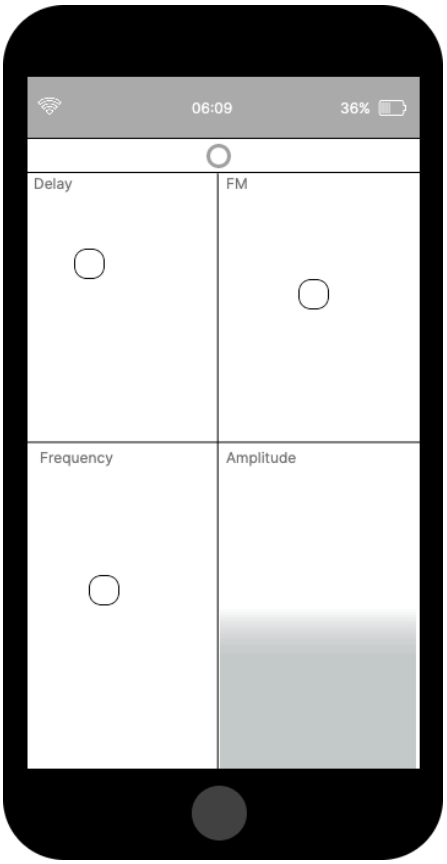

Fig. XVI: Design Prototype of the Instrument Page

5.4 Implementing the Components

5.4.1 Overview

Before integrating all the components into the final application, it is essential to establish several technical terms and connect them to the specifics of the project for clearer understanding. These terms include the foundational elements of web development: HTML, CSS, and JavaScript. Additionally, the concepts of frameworks and libraries are also addressed.

HTML (Hypertext Markup Language) provides the fundamental structure for the website's content and ensures that web browsers correctly render the appropriate elements. CSS (Cascading Style Sheets) define the aesthetic aspects of these elements, such as colors, shapes, and positioning. JavaScript, a programming language compatible with all browsers, introduces dynamic functionality to the website (Kumar 2018).

These technologies form the foundation of this project, complemented by the use of a framework and two libraries. The CSS framework Bootstrap is employed to facilitate the development of responsive websites with optimized efficiency (contributors, n.d.). Furthermore, the project incorporates two libraries: P5.js, which handles animations on the prompt page and the instrument's interface, and Tone.js, which manages the audio algorithms.

P5.js is designed as an educational resource that provides immediate access to creative coding, while also supporting more complex processes such as the creation of generative art. Its vibrant community, which offers extensive documentation and numerous examples, along with the ability to sketch ideas directly in the web editor, makes it a valuable tool for developing animations and user interfaces. (“About,” n.d.).

Since the project involves sound synthesis on the web, Tone.js is employed to manage this aspect of the application. This library offers a range of useful features, including pre-built synthesizers and effects, which streamline the creation of interactive online audio devices. In the context of this project, the built-in FM Synthesizer and Ping Pong Delay serve as the core components of the instrument provided by the platform (“Tone.Js,” n.d.).

5.4.2 Coding the Landing Page

The functionality of the index.html file, in which the code is implemented, is guided by the design and conceptualization of the landing page. This includes positioning the sentences developed during the design phase in various areas of the screen and establishing a hyperlink

system that connects to other sections of the application. As discussed in the design section, the former draws inspiration from John Cage's work, while the latter is essential for enabling navigation throughout the different components of the project.

To implement this functionality, several factors must be considered. First, the page must be divided into a suitable number of sections, each containing one or more randomly selected sentences positioned at a randomly selected point from a predefined array of possible points within the section. Additionally, it is essential to ensure that longer sentences are spaced sufficiently apart to prevent overlapping text. Furthermore, each sentence developed during the design process must function as a hyperlink directing users to different sections (subpages) of the application, with the exception of the introductory phrase, *"Welcome to Into the Deep End."* This sentence, instead of linking to a subpage, reloads the landing page, triggering a new arrangement of the elements in randomly selected positions.

```
const container = document.getElementById("text-container");
const screenWidth = window.innerWidth;
const screenHeight = window.innerHeight * 0.8;

// Calculate section width and height based on screen size
// For larger screens, spread out the content more
const columns = screenWidth > 768 ? 4 : 3;
const rows = screenWidth > 768 ? 4 : 3;

const sectionWidth = screenWidth / columns;
const sectionHeight = screenHeight / rows;
const maxTextWidth = sectionWidth * 0.8;
const coordinates = [];

// Generate possible x and y positions with more spread
const xPoints = [...Array(columns)].map((_, i) => sectionWidth * i + screenWidth * 0.05);
const yPoints = [...Array(rows)].map((_, i) => sectionHeight * i + screenHeight * 0.1);

// Function to check if a coordinate is already used or too close
function isCoordinateTaken(x, y, text) {
    // Calculate minimum vertical distance based on text length
    const minVerticalDistance = text.length > 30 ? sectionHeight * 0.8 : sectionHeight * 0.5;

    return coordinates.some(coord => {
        // Check if same X position (same column)
        const sameColumn = Math.abs(coord[0] - x) < sectionWidth * 0.5;
        // Check if Y positions are too close
        const tooClose = Math.abs(coord[1] - y) < minVerticalDistance;
        // Return true if both conditions are met
        return sameColumn && tooClose;
    });
}
```

Fig. XVII: Code Snippet from index.html

The JavaScript excerpt above from the *index.html* file demonstrates the calculation of

columns and rows based on the screen width of the user's device. It also illustrates the construction of arrays containing possible x- and y-coordinates within these sections, as well as the function responsible for checking whether a coordinate designated for sentence placement is already occupied.

5.4.3 Coding the Prompt Page

The primary objective in coding the prompt page is to accurately implement the three states defined during the design process. Upon loading, the initial state prompts users to tap anywhere on the screen to initiate the random selection of a prompt from the array. This functionality is achieved as shown in the code snippet below. By default, the Boolean variable *firstTime* is set to *true*, ensuring that the page initially displays the designated content for the first state. Upon the user's first interaction, the variable is set to *false*, preventing the behavior from repeating until the page is reloaded.

```
function touchStarted() {
    if (showPrompt) {
        resetAnimation();
    } else {
        pulseGrowth = 0;
        grower = width * 0.125;
        showCirc = true;
    }

    if(firstTime){
      firstTime = false;
    }
}

function displayPrompt() {
    canvas.hide(); // Hide the p5.js canvas
    let randomPrompt = prompts[Math.floor(Math.random() * prompts.length)];
    promptBox.innerText = randomPrompt;
    promptBox.style.display = "block"; // Show the prompt div
}


function resetAnimation() {
    promptBox.style.display = "none"; // Hide the prompt
    canvas.show(); // Show the canvas again
    pulseGrowth = 0;
    grower = width * 0.125;
    showCirc = true;
    showPrompt = true;
}
```

Fig. XVIII: Code Snippet from prompt.html

Since the core functionality of *prompt.html* is implemented using P5.js, the *draw()* function is essential. This function manages the page's animation and, as demonstrated in the code snippet below, controls the transition between the second and third state. To facilitate this, a Boolean variable called *showCirc* is used to trigger the loading state, during which a growing circular shape visually represents the random selection process from the prompt array. The transition to the final state is handled within an *if* statement, where the animation stops, the background is reset to white — clearing all previously drawn shapes — and the selected prompt is displayed.

```
function draw() {

  if (firstTime) {
      background(255);
      push();
      fill(0);
      textAlign(CENTER);
      textSize(16);
      textStyle(NORMAL);
      text("Click anywhere to draw a prompt", width / 2, height / 2);
      pop();
  }

    background(255, 30);

    if (showCirc) {
        growCirc.show(grower);
        grower += 1;
    }

    if (pulseGrowth > 2) {
        pulseGrowth = 0;
        grower = width * 0.125;
        showCirc = false;
        showPrompt = true;
        background(255);
        displayPrompt(); // Call function to display prompt
    }

    if (grower >= width * 0.25) {
        pulseGrowth += 1;
        grower = width * 0.125;
    }
}
```

Fig. XIX: Code Snippet no.2 from prompt.html

5.4.4 Coding the Instrument Page

The functionality of the instrument page is implemented using a combination of P5.js for the user interface and Tone.js for audio processing. The primary audio components are initialized within the *setupToneJS()* function. Tone.js offers a built-in oscillator with frequency modulation capabilities and a ping-pong delay with adjustable delay time, allowing for an immediate realization of the theremin's core functionality with additional parameters. Furthermore, the instrument's volume is initially set to a very low level to provide a controlled starting point.

```
function setupToneJS() {
    // Create a volume control
    volume = new Tone.Volume(-60); // Start quiet

    // Initialize FM synth (carrier + modulator)

    carrier = new Tone.FMOscillator({
        frequency: baseFreq,
        type: "sine",
        modulationType: "sine",
        harmonicity: 0,
        modulationIndex: modDepth
    }).connect(volume);

    // Create a ping pong delay effect
    pingPongDelay = new Tone.PingPongDelay({
        delayTime: delTime,
        feedback: 0.5,
        wet: 0.5
    });

    // Connect signal chain: carrier → delay → master output
    volume.connect(pingPongDelay);
    pingPongDelay.toDestination();
}
```

Fig. XX: Code Snippet from instrument.html

The instrument's control is managed within the *draw()* function of the P5.js library. Each user touch is stored in an array along with its corresponding x and y coordinates. A *for* loop iterates through this array every time the *draw()* function is executed, checking whether the touch points fall within the corresponding control fields. If they do, the associated values are used to modify the instrument's primary parameters, including volume and frequency (pitch), as well as the frequency modulation parameters — such as modulation depth and modulation oscillator frequency. Additionally, the digital delay parameters, including delay time, feedback, and the amount of delay effect applied to the signal, are adjusted accordingly.

```
for (let touch of touches) {
    // Frequency control - now using pentatonic scale
    if (touch.x < width * 0.5 - 15 && touch.y > height * 0.5 + 15 && touch.x > 15 && touch.y < height - 15) {
        frequencyRectX = touch.x;
        frequencyRectY = touch.y;

        // Use X position to select which note in the scale
        currentNote = floor(map(frequencyRectX, 15, width * 0.5-15, 0, justRatios.length));
        currentNote = constrain(currentNote, 0, justRatios.length - 1);

        // Use Y position to select which octave
        currentOctave = map(frequencyRectY, height-15, height * 0.5+15, 0, octaveRange);
        //currentOctave = octaveRange - currentOctave; // Invert so higher positions = higher octaves

        // Calculate the frequency from the just intonation scale
        baseFreq = calculateJustFrequency(currentNote, currentOctave);

        // Update carrier frequency
        carrier.frequency.rampTo(baseFreq, 0.02);
    }

    // Volume control
    else if (touch.x > width * 0.5 && touch.y > height * 0.5 && touch.x < width && touch.y < height) {
        volY = touch.y;
        let vol = map(volY, height, height * 0.5, 0, 1);
        // Convert to dB for Tone.js (0 = 0dB, 1 = silence)
        let volumeDB = map(vol, 0, 1, -80, 0);
        volume.volume.rampTo(volumeDB, 0.02);
    }

    // FM Modulation control
    else if (touch.x > width * 0.5 + 15 && touch.y > 15 && touch.x < width - 15 && touch.y < height * 0.5 - 15) {
        fmRectX = touch.x;
        fmRectY = touch.y;
```

Fig. XXI: Code Snippet no.2 from instrument.html

5.4.5 Coding the About Page

The final element of the application is a straightforward *tutorial* page featuring a single button. This button provides access to a PDF document containing excerpts from this work, offering users insight into the ideation and development process. The document includes information on the generation of prompts, their connections to academic research, and the functionality and components of the instrument. This feature was implemented efficiently using a minimalist button from the CSS Bootstrap framework, which links directly to the corresponding PDF file.

5.4.6 Temporary Deployment

To ensure both the accessibility of the code and the ability to test the application's functionality and design across various touch devices and by different users, the project is deployed as a GitHub Page (“Into the Deep End,” n.d.). All necessary files are stored in a dedicated GitHub repository, allowing for seamless access, collaboration, and iterative improvements (michaelxstark [2025] 2025).

These foundational elements establish the groundwork for user interface and user experience research. The primary objective of this research is to evaluate the application's functionality and design, providing insights that will inform and enhance its further development.

5.5 UI/UX Research in Digital Humanities

5.5.1 Overview

Before developing a research questionnaire, it is essential to examine the fundamental principles of UI/UX research and its role within the field of Digital Humanities.

The International Organization for Standardization (ISO) defines user experience (UX) as “a user’s perceptions and responses that result from the use and/or anticipated use of a system, product, or service” (“ISO 9241-210:2019(En), Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems,” n.d.). Additionally, the ISO describes user interface (UI) as “all components of an interactive system (software or hardware) that provide information and controls for the user to accomplish specific tasks with the interactive system” (“ISO 9241-210:2019(En), Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems,” n.d.).

The importance of well-designed interfaces aligns with the observations of Gibbs and Owens (2012) regarding the challenges faced in the Digital Humanities concerning the use and development of digital tools. The authors argue that due to a lack of intuitive and self-explanatory interfaces, only a limited number of scholars actively engage with these tools. They suggest that enhancing usability and accessibility could encourage broader adoption, ultimately transforming and enriching scholarly research practices.

A practical framework for achieving these goals is provided by Jakob Nielsen’s “10 Usability Heuristics for User Interface Design” (“10 Usability Heuristics for User Interface Design,” n.d.). Nielsen identifies key principles that enhance user experience by improving interface design. These principles include ensuring that systems provide users with clear and accurate feedback about their position within the application, using standardized terminology to maintain consistency, and designing interfaces that are clear and minimalist, allowing users to focus on their intended tasks without unnecessary distractions.

All of these aspects will form the foundation of the questionnaire, which serves as the centerpiece of the UI/UX research in this project.

5.5.2 The UI/UX Research Questionnaire

In addition to structuring the questionnaire around Nielsen's heuristics, obtaining meaningful results also depends on using clear and neutral language, incorporating a mix of question types (e.g., multiple-choice and open-ended questions), and ensuring the survey remains concise and focused ("How to Use Surveys for User Experience Research," n.d.).

Considering these factors, the survey consists of the following questions:

I.) *What is your first impression of the application?* (Open-ended question)
This question serves as an initial entry point into the questionnaire, allowing participants to freely express their immediate impressions of the application.

II.) *Did you find it easy to navigate through the different parts of the application?* (Multiple choice: 1 = not at all, 5 = very much)
This question assesses the effectiveness of the application's navigation system, specifically the choice to use a simple circular home button. It aligns with Nielsen's heuristic emphasizing the importance of ensuring users always know their location within an application ("10 Usability Heuristics for User Interface Design," n.d.).

III.) *Did the prompts help you generate new ideas for improvisation, or were they too cryptic?* (Multiple choice with three possible answers: a.) They inspired me right away. b.) It took time to get used to the style, but they eventually inspired me. c.) Not really — I would have preferred more focused prompts.)
This question evaluates the effectiveness of the prompts in stimulating creative ideas. Additionally, it relates to Nielsen's principle of using clear and comprehensible language to enhance user experience ("10 Usability Heuristics for User Interface Design," n.d.).

IV.) *Did you find the instrument helpful as a complement to the cognitive impulses provided by the prompts?* (Multiple choice: 1 = not at all, 5 = very much)
This question examines how participants perceive the integration of a practical, interactive element alongside the prompts, which are derived from digital humanities research on improvisation in electronic music.

V.) *How do you feel about the minimalist design?* (Multiple choice: 1 = not good, 5 = very good)
This question addresses Nielsen's guideline advocating for minimalist and focused design to

minimize distractions and improve usability (“10 Usability Heuristics for User Interface Design,” n.d.).

VI.) *Did you encounter any errors while using the application? If so, where?* (Open-ended)
This question solicits feedback on functionality and potential issues. It aligns with Nielsen’s heuristic that emphasizes not only displaying errors effectively but also proactively preventing them through careful design (“10 Usability Heuristics for User Interface Design,” n.d.).

VII.) *Do you have any suggestions or features you would like to see added to the application?* (Open-ended)
Like the introductory question, this final question provides an opportunity for participants to freely share ideas for future improvements. It also serves as a space for creative associations and reflections on the application’s potential development.

The survey itself is conducted using Google Forms, providing a straightforward evaluation method and an intuitive interface for participants. The participants come from diverse backgrounds but can be categorized into three main groups: musicians with experience in improvisation and electronic music/tools, musicians without such experience, and non-musicians with an interest in music and music technology.

5.5.3 Evaluation of UI/UX research survey

A total of 15 participants completed the survey, all of whom, as previously stated, have a connection to electronic music, music technology, and a fundamental understanding of musical improvisation. The following evaluation will analyze each question individually, followed by a summary contextualizing the findings in relation to both the application's interface and its overall functionality.

Question 1:
Given the focused number of participants, meaningful insights can be drawn from the first survey question without the use of topic modeling tools. When asked about their initial impressions of the application, participants' responses converged around a few key themes: the clean and minimalist design, the application's playful nature, and its invitation to experiment. These aspects were consistently well received and regarded as positive features of the application.

Question 2:

The second question evaluated the ease of navigation within the application. The findings reveal that 40% of participants found the application to be very easy to navigate. Additionally, 46.7% rated the navigation experience 4 out of 5, while the remaining 13.3% provided ratings of 2 or 3 out of 5.

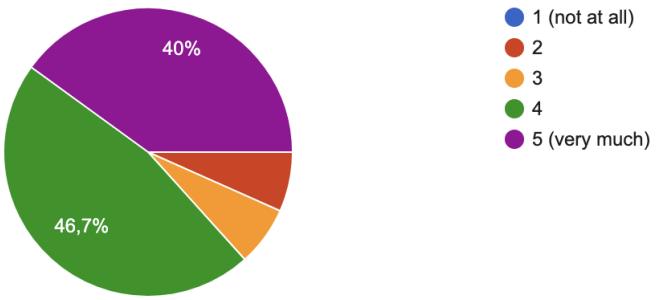

Fig. XXII: chart for question no.2 of UI/UX research questionnaire

Question 3:

When asked about the inspirational impact of the prompts, 60% of participants reported that they required some time to become accustomed to the style of cognitive impulses, while the other 40% found them immediately inspiring.

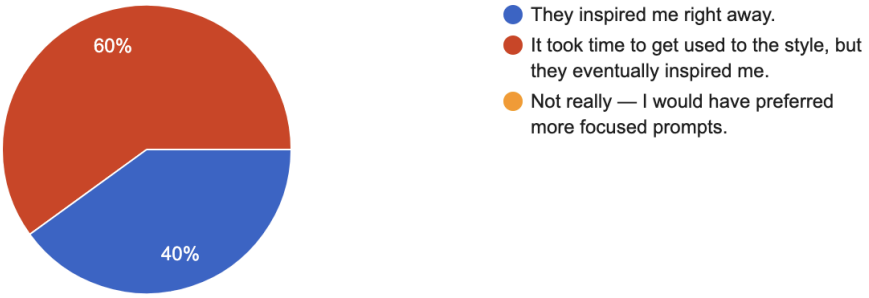

Fig. XXIII: chart for question no.3 of UI/UX research questionnaire

Question 4:

Given that the online instrument is a fundamental component of the platform, it is essential to evaluate user perceptions regarding the opportunity to incorporate a practical element into their engagement with improvisation. The results indicate that 40% of participants found the instrument highly beneficial, assigning it a rating of 5 out of 5. An additional 46.7% rated it 4

out of 5, while the remaining 13.3% evaluated the addition of the instrument with a score of 3 out of 5.

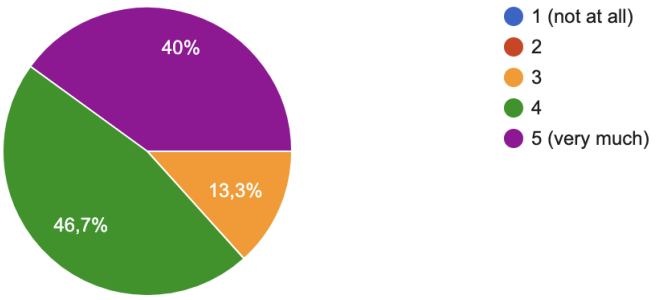

Fig. XXIV: chart for question no.4 of UI/UX research questionnaire

Question 5:

The project's minimalist design is another key aspect evaluated in the survey. Question 5 specifically assessed users' perceptions of this design choice. The results indicate that 86,7% of participants highly appreciated the minimalistic approach, giving it a full score of 5 points, while the remaining 13.3% rated it 4 points.

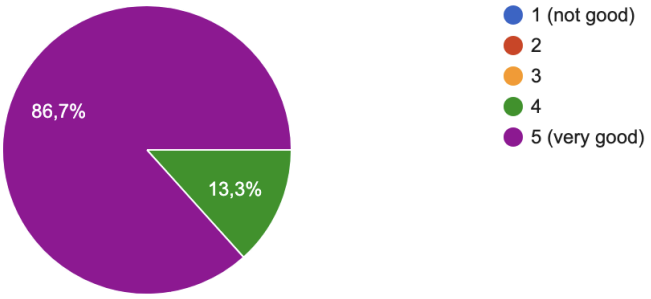

Fig. XXV: chart for question no.5 of UI/UX research questionnaire

Question 6:

The second-to-last question focused on whether users encountered any errors while using the application. Five participants left the response field blank, and six participants reported that they did not experience any issues during their interaction with the platform. The remaining four did not report problems with the application itself but indicated that they were unaware

of the need to set their phones to “loud” mode in order to hear the instrument.

Questions 7:

The final question invited users to share suggestions for further improving the platform. While some participants indicated that they had no additional input, several recurring themes emerged. First, two users proposed the addition of features that would allow them to record and export their performances on the instrument. Second, one participant recommended enhancing the effectiveness of the prompts by increasing the number available to each user. Additional suggestions included incorporating a sampling option or a conventional keyboard. Finally, one participant proposed adjusting the default amplitude settings of the instrument.

In summary, several key insights have emerged from the survey that will inform the further development of the platform. The first notable finding is that users generally respond very positively to the minimalist design, which stands out in their initial impression of the application. Additionally, the inclusion of the instrument as a practical outlet for users' creative thoughts was well received, with many viewing it as a playful feature, though there is interest in expanding its functionality. The style of the prompts was appreciated by 40% of the participants, while the other 60% required more time to fully engage with them. Moreover, the fixed number of prompts was identified as an area for improvement in future versions of the application. Possible implementations and their potential impact will be discussed in the final section of this work.

Chapter 6 — Conclusion and Outlook

The primary objective of this thesis was to develop an online platform dedicated to the practice and exploration of improvisation in electronic music. To position the project within the field of Digital Humanities, the research combined literature-based inquiry with quantitative audio analysis. This was complemented by a detailed documentation of the development process, which included translating the multidisciplinary research into prompt-like impulse statements inspired by the *Oblique Strategies* cards created by Brian Eno and Peter Schmidt. Additionally, the project involved the design and implementation of an online instrument — drawing conceptual reference from the early electronic instrument, the Theremin — to support the cognitive dimension introduced by the impulse statements. Ultimately, a functional version of the platform was successfully deployed online ("Into the Deep End," n.d.).

Although presented in a concise form, the discussion of the fundamental aspects of musical improvisation clearly demonstrated the complexity of defining the practice. The boundaries between improvisation and composition are often ambiguous, and perceptions of these distinctions have evolved over time. A unifying perspective is offered by Alperson, who argues that improvisation and composition are logically interdependent, thereby eliminating the need for a rigid boundary between the two (Alperson 1984).

The complex nature of improvisational practices was further emphasized through a brief historical overview. This section outlined the evolution and fluidity of the field, highlighting several key developments that have shaped the practice over time. These include the role of counterpoint and basso continuo in earlier musical traditions, as well as the emergence of collective improvisation in jazz ensembles.

This exploration was extended by highlighting instances of improvisational practices in diverse musical traditions worldwide, as well as across various contemporary music genres.

Moreover, the discussion was expanded to include cognitive, societal, and aesthetic dimensions of musical improvisation. It became evident that improvisation requires not only specific skills — such as deep listening and the ability to communicate within a shared musical language — but also promotes egalitarian dynamics in group settings and facilitates the emergence of flow states. Furthermore, the inherent spontaneity of the practice necessitates a distinctive aesthetic approach that is integral to the genre.

The subsequent discussion on improvisation within electronic music further deepened the understanding of improvisation as a complex and multifaceted practice, particularly when augmented by the expanded possibilities offered in electronic music contexts.

To illustrate this point, a brief historical overview of electronic music was provided, highlighting the interdependence between technological innovation and the genre's development. Additionally, influential figures and their contributions were introduced to contextualize the evolution of ideas within the field.

With the final application — and particularly the accompanying instrument — in focus, the fundamental components of audio synthesis were introduced.

The following section of the discussion addressed key aspects of improvisational practices in electronic music. Topics ranged from the challenges and opportunities associated with improvising in non-performative settings, such as sound studios, and with instruments lacking clearly defined playing conventions, to the complexities of interpreting bodily gestures within electronic music contexts. Additionally, the investigation explored the role of novel improvisational partners — such as computers and music robots — as well as the expanded sonic and control possibilities enabled by computer-based systems.

To incorporate a quantitative dimension into the discussion and to reinforce the project's connection to the field of Digital Humanities, several audio analyses were conducted on recordings of two improvised performances: an excerpt from Keith Jarrett's *Köln Concert* and a corresponding excerpt from Autechre's *NTS Sessions*. The objective was not to undertake a large-scale quantitative study, but rather to contribute a representative analytical component to support the content of the final application. The two excerpts — selected for their contrasting stylistic and technological characteristics — were used to highlight fundamental differences between acoustic and electronic improvisation. Notable distinctions emerged in several areas, including the frequency spectrum (significantly broader in the electronic piece), the presence of identifiable musical scales (observable only in the acoustic performance), and variations in rhythmic onset distribution and perceived loudness.

The insights gained from both the literature-based research and the quantitative audio analyses served as foundational elements for the development of the final application. The documentation of the development process began by outlining general considerations regarding the creation of digital applications and devices within the context of the Digital Humanities. This included a discussion on the role of tools as instruments for knowledge generation and the criteria they must meet to effectively fulfill this function.

In the next phase, the knowledge acquired from the preceding research was contextualized within the framework of the *Oblique Strategies* developed by Brian Eno and Peter Schmidt. This was achieved by extracting key insights from the research and distilling them into prompt-like statements that emulate the open-ended, thought-provoking style characteristic of the intellectual reference. A total of 25 prompts were formulated, providing a solid foundation for the current iteration of the application, where they are randomly selected on a dedicated sub-page of the web platform.

The next component of the application to be contextualized through a historical reference from electronic music was the accompanying instrument. The historical origins and functionality of the Theremin were outlined, along with a rationale for its adaptation to suit the touchscreen-based format of the application. To enhance its sonic capabilities — beyond the limitations of the original instrument — a delay effect and frequency modulation features were integrated. Both techniques were examined in detail in the relevant sections of the documentation.

The final component of the application to be contextualized was the landing page, which incorporated a visual reference to John Cage's *Lecture on Nothing*.

The discussion then progressed with the introduction of core design principles and visual mockups of the application, created using the design software *Lunacy*. The primary design principle adopted was minimalism, reflecting the reduced aesthetic characteristic of all the intellectual references informing the project.

The technical documentation concluded with an overview of the components required to implement the application, including HTML, CSS (with particular emphasis on Bootstrap), and the JavaScript programming language. Additionally, the libraries Tone.js and P5.js were employed to handle the audio functionality and to develop significant portions of the user interface, respectively. Key sections of the code that enable core functionalities of the application were also discussed, providing insight into the underlying cognitive processes that informed the design and implementation.

The final component of the project — which also serves as a stepping stone for future development — was the conceptualization and implementation of UI/UX research through a dedicated questionnaire. A concise set of questions was developed to evaluate various aspects of the application, including interface design, functionality, the relevance of the prompts, the role of the instrument, and suggestions for potential improvements.

The insights gained from the questionnaire revealed a general approval of the

application's minimalist design and its playful approach to bridging cognitive prompts with practical execution. However, ratings of 2 and 3 out of 5 regarding navigational ease indicated an area for improvement. In response, the landing page was redesigned to highlight interactive elements by visually emphasizing that each section functions as a hyperlink to different parts of the application. The prompt style was fully appreciated by 40% of participants, while the remaining 60% reported needing time to become accustomed to it. This response is considered acceptable, given that the stylistic approach aligns closely with the intellectual reference and is thus integral to the application's conceptual identity. Another prominent area for improvement identified through the questionnaire was the handling of audio. Some users noted that it was not immediately clear how to activate the instrument or found that the initial volume was too low. These issues were addressed by adding a start screen to the instrument page, which instructs users to switch their device to loud mode and tap the screen to activate audio. Furthermore, the instrument's default volume was adjusted to start at half of the maximum amplitude, ensuring it is audible without being overwhelming.

Additional suggestions — such as the ability to record, sample, loop, and export performances — will be considered for future iterations of the project. This indicates that the platform positions itself as an evolving tool for the ongoing exploration of improvisational practices in electronic music, continually adapting to reflect the inherently fluid nature of the field.

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Zusammenfassung

Diese Arbeit dokumentiert die konzeptionelle Entwicklung und praktische Umsetzung einer interaktiven, informativen Web-Applikation für und über Improvisation in der elektronischen Musik. Ausgangspunkt bildet eine Literaturanalyse, die sich mit den historischen, gesellschaftlichen, kognitiven und ästhetischen Dimensionen musikalischer Improvisation auseinandersetzt. Im weiteren Verlauf richtet sich der Fokus auf die erweiterten Ausdrucksmöglichkeiten improvisatorischer Praxis in der elektronischen Musik, die maßgeblich durch technologische Entwicklungen geprägt sind. Zur vertieften Erfassung der spezifischen Merkmale dieser Spielart werden quantitative Audioanalysen durchgeführt, die Unterschiede in Rhythmik, melodischer Struktur und Klangfarbe zwischen akustischen und elektronischen Improvisationen untersuchen. Die aus der Literatur- und Audioanalyse gewonnenen Erkenntnisse bilden das konzeptionelle Fundament für die Entwicklung der finalen Applikation. Diese vereint impulsgebende Statements, die aus den zuvor erarbeiteten theoretischen und analytischen Ergebnissen abgeleitet sind, mit einem Online-Instrument, das Nutzer*innen ermöglicht, kognitive Impulse unmittelbar in musikalische Praxis zu übersetzen. Ziel der Arbeit ist es, theoretische und praktische Perspektiven aus den Digital Humanities und der Musikwissenschaft zu verknüpfen und zugleich eine neue Sichtweise auf improvisatorische Praktiken in der elektronischen Musik zu eröffnen.