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Exploring Hardanger Fiddle Performance Patterns Through Interactive Computational Tools

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May, 2021

Master's programme in Music, Communication & Technology

Abstract

There exists a modest amount of computational research on traditional Scandinavian fiddle performances. The MIRAGE research project is currently contributing to this scientific body utilizing a transdisciplinary approach. A way to mitigate challenges inherent to transdisciplinary research approaches is to develop tailored technologies that seek to increase the availability of expertise and knowledge across disciplines. This thesis presents the development and evaluation of two software prototypes that integrate contemporary research perspectives on the complex rhythmical structuring of traditional *springar* performances[1], investigating how we can design interactive computational tools that explore Hardanger fiddle performance patterns.

The evaluation featured both qualitative and quantitative methods, consisting of several operational tests and an online questionnaire. Results show a demand for more tailored technologies in the field of musicology, particularly for tools capable of revealing the complex interrelations between musical dimensions through interactive and visual means. Additional findings highlight other design considerations for tools aiming to increase the availability of computational music research in the field of musicology, such as cross-compatibility and integrated features that actively facilitate nuanced interpretation processes.

[1]For a condensed version of this thesis, featuring a brief video demonstration of the proposed toolkit, visit this blog post.

Acknowledgement

First of all, I would like to thank my supervisor, Olivier Lartillot, for being involved in almost every aspect of this thesis, guiding the process from the very beginning. His wast knowledge and passion for music research is truly inspiring. Being part of the MIRAGE team this last year has been a wonderful learning experience for a novice like myself.

I also wish to thank my co-supervisors, Anders Elowsson and Professor Mats Sigvard Johansson, for guiding me through the scary forests of traditional Scandinavian folk music studies and MIR research, lending me their precious time and wisdom.

A special thanks to Stefano Fasciani, associate professor, for being an excellent teacher and mentor. His dedication and influence on the MCT programme has been invaluable, making the badge of MCT something to be worn with pride in an upright posture. This master's programme has truly changed my life for the better, many thanks to him.

Finally, I am grateful for the emotional support and stability from my loving partner, Silje Alnes, especially in these last few years, speaking words of wisdom in times of pandemics.

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Chapter 1

Introduction

This thesis presents the development and evaluation of two interactive computational tools that integrate contemporary research perspectives on the complex rhythmical structuring of Hardanger fiddle *springar* performances, in collaboration with the MIRAGE research project. The thesis begins with an introduction, clarifying the research question, contribution and some key terminology. Second, the scientific fields of computation music analysis and Hardanger fiddle performance studies are presented to contextualize the thesis approach and current state-of-the-art of MIRAGE. After establishing the necessary scientific backdrop, the thesis methodology is considered, featuring a detailed system description followed by an in-depth account of the evaluation procedure. Finally, the evaluation results form the basis for a critical discussion on the methodological framework and the toolkit design before the thesis is concluded with reflections on key challenges and future work.

1.1 Research Question and Objectives

No comprehensive understanding of music is without thorough consideration of its execution and performance, aesthetic and expressive experiences unique to their moment in time. Analyzing musical performances is a challenging and emergent field of computational music research, aiming to reveal performance patterns and link them to musical contexts (Lerch et al., 2020). The MIRAGE research project is contributing to this scientific body, currently addressing the modest amount of computational research on traditional Scandinavian folk music (Lartillot, 2021b). This subject presents unique challenges to computational music research, requiring expertise and perspectives from a range of scientific disciplines, such as cognitive science, musicology and library sciences.

A way to mitigate challenges inherent to such transdisciplinary research approaches is to develop tailored technologies that seek to increase the availability of expertise and knowledge across disciplines. In recent years, several computational frameworks and core development libraries have been proposed that address the ongoing demand for comprehensive, well-designed and reliable research tools for music research and education, such as the MiningSuite (Lartillot, 2011), Music21 (Cuthbert & Ariza, 2010), and the Musical Gesture Toolbox (Jensenius et al., 2005). Studies have also indicated that most tailored technologies for music performance assessment are unreliable in educational settings, suggesting that further research is needed to evaluate the usability of research tools that explore musical performances (Eremenko et al., 2020). Inspired by these contemporary challenges, and my ability to acquire detailed Hardanger fiddle performance data from MIRAGE, the research question became:

- How can we design interactive computational tools to explore performance patterns in Hardanger fiddle music?

Upon further reflection on the research question, the thesis goal became to develop a toolkit that would seek increase the availability of computational music research in the field of musicology and Scandinavian folk music studies. For this approach to be feasible within a limited time frame, additional objectives were needed to further compartmentalize the research question and ensure that the proposed toolkit integrated contemporary research perspectives into its design. Therefore, three research objectives (design concepts) were defined, based on contemporary Scandinavian folk music studies and the current capabilities of the MIRAGE research project.

1-2. The tools should enable **structural** and **multi-dimensional** perspectives on the unique rhythmical structuring of Hardanger fiddle *springar* performances.

In the current context, if a software tool enables a structural perspective, it can detect or present meaningful musical structures, such as melodic phrases, rhythmical figures and motifs. On the other hand, if a tool enables a multi-dimensional perspective, the software can investigate relationships between various musical dimensions, such as how the rhythmical structuring is related to pitch, etc. By separating these two design concepts as much as possible in the development and evaluation stages of the thesis, a more systematic and precise study could be administered, reflecting the scarcity of prior research on the subject matter. Therefore, an additional goal became to approach the research question by designing prototypes that enabled structural and multi-dimensional perspectives separately, before identifying weaknesses in their general design concepts.

3. The tools should feature **interactive** and engaging user interfaces.

Interactivity was considered a running theme throughout the study, shaping most system features and toolkit design procedures. Although interactivity usually refers to the ability to engage with software, the current context operates with a slightly extended definition, encompassing aesthetical design and other visualization techniques.

1.2 Contribution

This study aims to increase the availability of computational music research in the field of musicology. Specifically, the techniques, methods and novel designs presented offer contributions to music-related research areas such as computational music analysis, music performance analysis, human-computer interaction and audio programming. Also, by investigating how to design tools that explore performance patterns in traditional Norwegian folk music, the thesis offers a small contribution to the preservation and modernization of important cultural heritage, and to Scandinavian folk music studies in general. Finally, through promoting a toolkit with a range of interactive and user-friendly features, the thesis' contribution extends beyond the purely scientific domain into more creative and educational areas, such as music performance assessment.

The author hopes that the thesis provides a valuable assessment of computational tools designed to explore performance patterns in traditional Norwegian folk music, and that it succeeds in generating a deeper appreciation for Scandinavian folk music by increasing public knowledge and understanding of Hardanger fiddle performance patterns.

1.3 Key Concepts

In an effort to address the specialized theme and transdisciplinary scope of the study, a set of central analytical units are defined preemptively. Specifically, the definitions presented aim to clarify the basic rhythmical hierarchy in Hardanger fiddle music, terminology that will be frequently referred to throughout the thesis.

- **Beats** - The musical beat is defined as the basic unit of time, consisting of recurring temporal events that, together, constitute the musical measure.

- **Measure** - A musical measure (or "bar") is a grouping or temporal organization of beats, whose group size is defined by the compositions time signatures (musical meter), as illustrated in Figure 1.1.

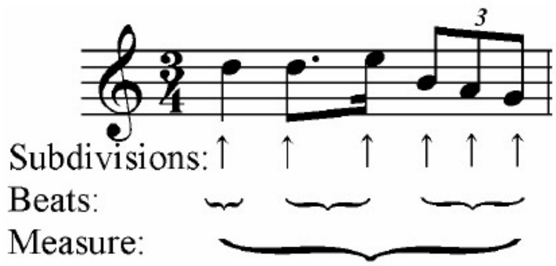


Figure 1.1: The hierarchical division of rhythmic levels. illustration and figure by Mats Johansson (Johansson, 2009, p.96).

- **Motifs** - Following contemporary performance studies on Hardanger fiddle music, motifs are defined as coherent melodic units (or phrases) often subjected to repetition throughout compositions (Johansson, 2009, p.100). Within *springar* traditions, whose rhythmic and temporal structuring is a key aspect of this study, these motivic units often extend over the course of two measures, as illustrated in Figure 1.2.

Figure 1.2: Excerpt of a *Tele-springar*, "Igletveiten", highlighting the two-measure motivic units (Johansson, 2009, p.101). Performance by Bjarne Herrefoss and transcription by Mats Johansson.

- **Timing patterns** - The concept of a timing pattern is defined as a collection of beat positions (onsets) and lengths (durations), often subjected to repetition, used to investigate the temporal characteristics of beat groupings in various musical structures as motifs and measures.

Chapter 2

Background

This chapter establishes the contextual background for the thesis through introductory accounts of a selection of scientific fields and research. First, an introduction and historical perspective on Computational Music Analysis (CMA) is presented with emphasis on current Music Information Retrieval (MIR) research. Then, core challenges related to Music Performance Analysis (MPA) are highlighted through examples of real-world applications implementing MIR and MPA-related research. Second, Hardanger fiddle performance studies is considered, beginning with a brief historical introduction followed by an in-depth account of the scientific investigation of asymmetrical timing patterns in traditional *springar* styles. Third, the MIRAGE research project is presented, highlighting the methodological framework, current research on traditional Scandinavian folk music, and the project's intended impact to musicology and societal institutions.

2.1 Computational Music Analysis

Both computational and more traditional music analysis help us solve problems, focusing on musical works through methods of comparison (Anagnostopoulou & Buteau, 2010, p.75-76). Computational music analysis is unique in its ability to render specific analytical tasks possible that would otherwise be considered impossible (Schüler, 2005, p.32).

2.1.1 Historical Overview & MIR

The progressive technological advancements of the mid-twentieth century, along with the conception of information theory, enabled new paradigms of scientific and computational exploration. The history of CMA is directly related to the history and development of computer science (Schüler, 2005, p.34). Although early work was often concerned with identifying musical styles and genres using stochastic processes and other statistical probability theories, technological advancements soon enabled the computational exploration of more complex musical properties, in particular through harmonic and structural analysis (Lartillot, 2021a, p.145-149).

Today, inter-and transdisciplinary approaches are considered true hallmarks of twenty-first-century systematic music research, necessary expansions of a sector that has high innovative, creative, economic and personal value. Computational music analysis is intertwined with most contemporary musicological disciplines, assisting the development of rich descriptions of music and providing stronger empirical foundations to historical evidence.

While CMA usually considers individual musical works, Music Information Retrieval is primarily concerned with the extraction and inference of meaningful features from larger corpora of music and the development of search and retrieval schemes (Anagnostopoulou & Buteau, 2010, p.77). By intersecting various scientific fields, such as musicology, sociology, machine learning, digital signal processing and library science, MIR-related research is particularly suited for addressing many real-world challenges (Schedl et al., 2014, p.128, 143). Recent MIR applications have shown promising results retrieving quite complex and abstract musical structures, such as motifs, using a variety of computational approaches (Lartillot, 2021a, p.156). AI and machine learning have also made significant contributions in this field, addressing complex issues such as modality modeling (Elowsson & Friberg, 2019) and audio source separation (Pardo et al., 2018).

2.1.2 Music Performance Analysis

Music Performance Analysis expands on the methodological and technological frameworks of CMA and MIR, focusing on the performer and the unique characteristics of musical performances (Lerch et al., 2020). By investigating interrelations between performance parameters, practices, and musical structures, MPA enables comprehensive scientific exploration into how listeners perceive music and how performers communicate and shape the musical content.

MPA and MIR-related research has extended beyond the purely scientific domain, influencing a range of real-world applications. This influence is perhaps most apparent in educational settings where interactive tools for music training and performance assessment, such as Yousician[1] and Music Prodigy[2], actively incorporate MIR-technologies like polyphonic pitch tracking for singing practice and intelligent music production systems. However, the lack of standardized assessment criteria for evaluating musical performances remains a central issue to such application development, having negative ramifications for the automated feedback delivery systems (Waddell et al., 2019). Current MPA studies have also suggested that more research is needed to evaluate the usability of tools that explore musical performances (Eremenko et al., 2020).

In a broader sense, these examples constitute more fundamental challenges to MPA and MIR-related research, highlighting the demand for better and more precise conceptual and computational frameworks for understanding the mechanics of and behind musical performances. While still being an active and on-going field of research, several promising contributions have been made in recent years, such as the MinigSuite (Lartillot, 2011) and Music21 (Cuthbert & Ariza, 2010), aiming to better articulate the relationship between the audio signal and symbolic layers, as well as increase the availability of computational music research in the field of musicology.

Computational approaches to traditional and world music analysis music is another growing field of music performance research, bringing together computer scientists, musicologists and ethnomusicologists[3]. Given the scarcity of computational research on non-western and traditional folk music performance, this area presents unique opportunities for increasing the cultural

[1]http://www.yousician.com

[2]http://www.musicprodigy.com

[3]http://www.folkmusicanalysis.org

diversity of MIR and MPA research, potentially decreasing algorithmic biases with a democratizing effect (Lerch et al., 2020).

2.2 Hardanger Fiddle Performance Studies

The Hardanger fiddle is a modified mix of the sixteenth-century Italian violin and older string instruments from the middle ages, consisting of a characteristic build and additional sympathetic/resonant strings. The fiddle has achieved similar cultural status in Norway as the stave churches and Viking ships, even bearing similar wooden ornaments, and its practices are studied in several scientific contexts (Sevåg & Sæta, 1992, p.35-37).

2.2.1 Historical Overview & Springar

Although Norwegian folk music traditions can be dated back to the seventeenth century, the cultural term originated with the progressive movements of the European romantic (Beal, 1984, p.237). In nineteenth-century Europe, cultural and nation-building projects addressed the destabilizing and alienating consequences of modernization and industrial development by constructing national identities anchored in traditional values (Nyhus & Aksdal, 1993). In Norway, rural and farming communities became symbols of national authenticity which led to country-wide systematic documentation of various folk traditions and practices. Although historical documents can date the use of the Hardanger fiddle back to the seventeenth and eighteenth-century, it was not until the romantic before the instrument achieved widespread recognition.

Hardanger fiddle music is often referred to as traditional dance music, forming an intimate and dialectic relationship with traditional dances such as *springar*, *gangar*, *rull* and *halling*. Each dance style consists of highly regional stylistic features, variations that are highly reflected in the fiddle playing style, often expressed rhythmically in the form of alternative accentuation and timing patterns. In the mid-twentieth century, the abundance of these localized styles influenced new naming conventions that combined geographical location with styles, such as *Numedals-gangar* and *Vestlands-springar*.

The *springar* dance is considered one of the oldest traditional couples dances in Norway and remains one the most commonly practiced (Beal, 1984, p.237). Most *springar* styles are rhythmically structured in triple meter (3/4) accompanied by solo Hardanger fiddle performances. Some regional variants of *springar*, such as *Tele-springar*, *Valdres-springar*, and *Halling-springar*, possess the interesting stylistic features of asymmetrical/irregular rhythmic structuring of the musical beats.

2.2.2 Asymmetrical Timing Patterns

The asymmetrical timing patterns native to certain *springar* styles refer to the systematic unevenness in the duration and position of the musical beats, as illustrated in Figure 2.1 (Sevåg & Sæta, 1992, p.51). These timing patterns are commonly organized into durational categories where each beat is given a label based on its relative duration within the measure, such as ”long-average-short”, ”long-long-short”/”short-long-average” or ”short-long-long”. For *Tele-springar*, *Valdres-springar*, and *Halling-springar*, the asymmetrical timing patterns constitute the basic framework for the musical performances and interactions.

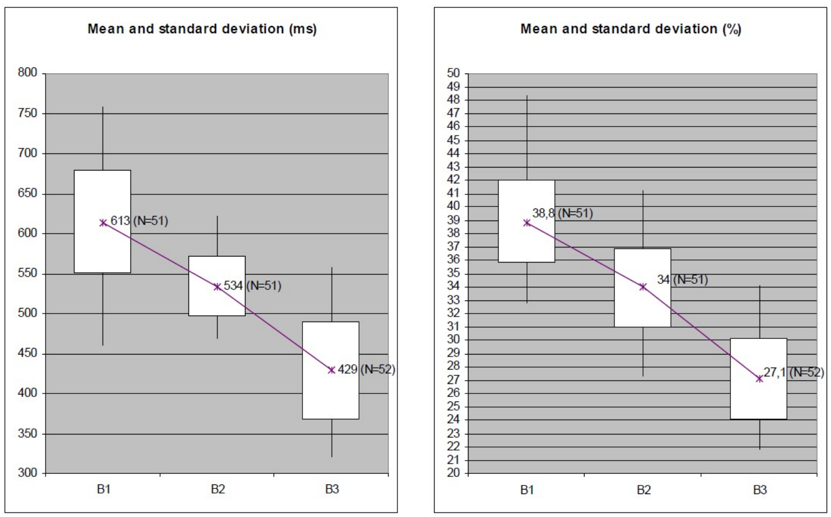


Figure 2.1: Beat duration data from ”Igletveiten”, a *Tele-springar* with ”long-average-short” asymmetry pattern. The *-marks and the lines between them represent the mean, the white boxes the two-sided standard deviation, and the range is indicated by the vertical lines (Johansson, 2009, p.182). Performance by Bjarne Herrefoss, live recording from a concert at Gol Campingsenter 08-03-1991. Archive recording from *Folkemusikksenteret i Buskerud*. Data and analysis by Mats Johannsson.

Early performance studies interpreted this temporal unevenness as constituents of uneven time signatures, such as $2\frac{1}{2}/4$ meter or $\frac{1}{2}+2/4$ meter, based on aural estimations (Haugen, 2014, p.29). Later, these perspectives were substituted by other approaches that emphasized, among other things, the correspondence between the musical rhythm and the dance rhythm, often using quantitative and tailored methods in their investigations, as Figure 2.2 illustrates. More experimental frameworks have since been proposed, for instance modeling asymmetrical Hardanger fiddle timing through algorithmic tempo-variations and frequency modulation (Waadeland, 2000).

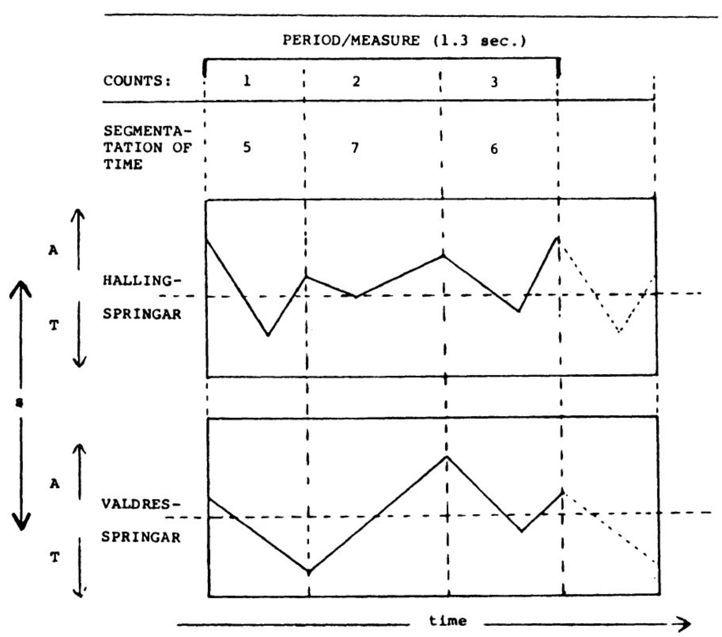


Figure 2.2: Some of Blom and Kvifte's early exploration of the dialectic timing relationships between *springar* styles involved depicting liberation curves and "space-force-time" correlations. The concept of "TA" here refers to rhythmic movements, where T (thesis) is a lowering downbeat and A (arsis) is a rising upbeat (Blom & Kvifte, 1986, p.504).

Despite generally conforming to a set of durational categories, as previously mentioned, asymmetrical Hardanger fiddle performances display wide variability in the absolute and relative durations of the beats and measures

(Johansson, 2017, p.82). In an attempt to better understand the mechanisms of and behind these expressive variations, recent performance studies have further analyzed the link between melodic and rhythmic structuring in *springar* performances. This research has shown that beat-level timing variations seem to be related to "melodic-rhythmic" structures in the sense that particular motivic segments are associated with particular timing profiles. This is particularly evident when a motif is repeated with the same timing profile, as illustrated in Figure 2.3. This melodic-rhythmic coherence has also been shown to influence note-level timing, having a vital role in dictating how individual notes and phrases are associated with varying beat durations.

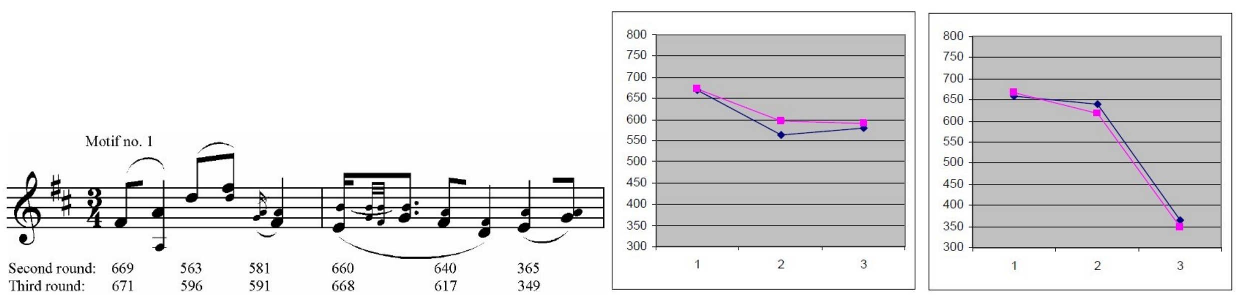


Figure 2.3: Analysis excerpt of "Igletveiten", a *Tele-springar* performance showing beat-level timing consistency throughout repetitions of a motif. The two graphs correspond to the two parts of the repeating motif (measure 1 and 2) with musical beats on the X-axis and millisecond duration on the Y-axis, while colors indicate repetitions. Analysis by Mats Johansson (Johansson, 2009, p.189).

The results pinpoint that most conventional approaches fail to recognize how structural and other expressive features influence beat durational patterns in Hardanger fiddle performances. Using measures and beats as analytical units should therefore serve an additional purpose of identifying relationships between melodic and rhythmic structures (Johansson, 2009, p.100).

More practice-oriented perspectives on Hardanger fiddle performance studies also support the notion that beat duration patterns are interdependent on a range of musical dimensions and parameters. These perspectives investigate and categorize fundamental stylistic aspects by predominantly looking at performance practices, such as bowing, fingering, foot-stomping, player intention and interpretation, as well as other expressive gestures (Johansson, 2009, p.2). Such practice-oriented studies have examined a wide variety of topics related to Hardanger fiddle performances, such as how finger placements affect melodic and rhythmic structures (Lien, 2020), and how bowing cycles communicate rhythm to dancers and can have a considerable impact on performance variations (Kvifte, 1987). Also, advancements in CMA and motion capture technologies have enabled more comprehensive studies by combining audio and visual cues, exploring subjects such as how foot-stomping is related to microtiming (Haugen, 2015).

2.3 MIRAGE Research Project

MIRAGE is a transdisciplinary research project dedicated to studying a range of musical styles and phenomena, incorporating traditional musicology, cognitive science, signal processing and artificial intelligence (Lartillot, 2021b).

2.3.1 Project Overview

MIRAGE's project goal is to improve computational understanding of music by conceiving new, accessible and engaging technologies. The research objectives include addressing how we can design computational systems that generate detailed and rich descriptions of musical dimensions, what kind of music analysis current computational technology can facilitate, and how these technologies can model music perception. By acknowledging the complexity inherent in any musical discourse and expression, MIRAGE places surplus consideration onto the interrelatedness between musical dimensions and practices in their research methodology. The project proposes to develop novel technologies for transcribing musical performances and systems to analyze such transcriptions based on careful considerations of musicological and cognitive perspectives. Collectively, these systems will seek to improve our ability to capture subtleties in musical language, map performance practices, and enable new musicological perspectives. Considering the comprehensive and transdisciplinary task, MIRAGE is organized into 5 distinct work packages:

- **WP1** - New Methods for Automated Transcription
- **WP2** - Comprehensive Model for Music Analysis
- **WP3** - New Perspectives for Musicology
- **WP4** - Theoretical and Practical Impacts on Music Cognition.
- **WP5** - Technological and Societal Repercussions.

2.3.2 Current Research

MIRAGE is currently preoccupied with studying traditional Scandinavian folk music performances and practices, building on cognitive, historical and contemporary musicological perspectives. This task presents a unique set of computational challenges, especially considering the complex relationships between performance practices and musical parameters in traditional Scandinavian folk music.

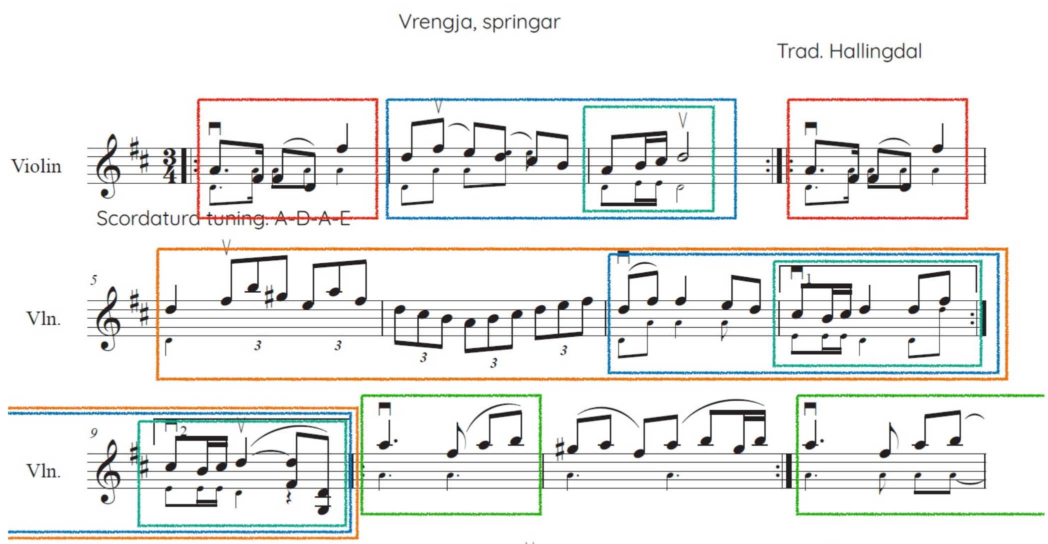


Figure 2.4: Computational detection of repeating sections and phrases in a *Halling-springar* called "Vrengja". Performance and subsequent transcription by Olav Luksengård Mjelva, analysis and color-coded visual representation by Olivier Lartillot.

The project research on Hardanger fiddle performances aims to generate high-dimensional performance transcriptions incorporating accurate polyphony, the metrical position of notes, ornamentation cues and other expressive features. Also, tailored systems for structural analysis and segmentation are currently in development, identifying repeating sections, phrases and motivic segments, as illustrated in Figure 2.4.

2.3.3 Intended Impact

The novel technologies developed by MIRAGE have the potential to contribute to music-related research and society in general (Lartillot, 2020). For instance, computational research on traditional folk music can contribute to libraries and other archival institutions with refined storage applications that can improve the conservation of valuable cultural heritage. The technologies also have the capability of increasing public music appreciation and data accessibility.

To musicology, MIRAGE's most apparent contribution is through the development and implementation of advanced AI and signal processing algorithms for music analysis that aim to strengthen our ability to explore musical complexity. In a more scientific sense, MIRAGE can potentially influence musicological research by seeking answers to several theoretical problems, specifically those related to formalization in music analysis.

2.4 Summary

To summarize, the field of Music Performance Analysis (MPA) present new challenges to computational music research, expanding on the methodological and technological frameworks of CMA and MIR, focusing on musical performances. Current MPA studies have suggested that more research is needed to evaluate computational tools for musical performance assessment, highlighting the demand for more precise conceptual and computational frameworks that increase our understanding of the mechanics behind musical performances.

The unique rhythmical structuring of traditional Norwegian folk music has interested Scandinavian folk music researchers for some time, exhibiting a great deal of temporal variability despite the music's intimate relationship with various traditional dances. Recent studies have shown that beat-level timing variations in Hardanger fiddle *springar* performances seem to be related to "melodic-rhythmic" structures, in the sense that particular motivic segments are associated with particular timing profiles, suggesting that structural and other expressive features influence beat duration patterns. In other words, the complex rhythmical structuring of Hardanger fiddle performances is interdependent on a range of musical dimensions and parameters.

There exists a modest amount of computational research on traditional Scandinavian folk music. MIRAGE is currently contributing to this scientific body, studying Hardanger fiddle performances and practices using CMA, MIR and MPA approaches, building on contemporary musicological performance studies and practice-oriented perspectives.

Chapter 3

System Description

This chapter presents two interactive computational tools that enable structural and multi-dimensional perspectives on the complex rhythmical structuring of Hardanger fiddle *springar* performances. First, an account of the Hardanger fiddle performance data is given with emphasis on the MIRAGE processes responsible. Second, a detailed description of the toolkit architecture is presented, highlighting primary functionalities.

3.1 Overview

The toolkit consist of three modules implemented in Max/MSP/Jitter[1](commonly referred to as as Max), using the Bach library[2] with additional JavaScript code, environments chosen for their relevance and excellent prototyping capabilities. The first module features a graphical score representation with

[1]https://cycling74.com/
[2]https://www.bachproject.net

various interactive editing capabilities. The second module features a plotting interface, enabling users to explore how timing patterns are related to motivic structuring. The third module consists of a similar plotting interface, enabling users to investigate parameter relationships across regions that share similar timing patterns. All modules are designed and based on specific Hardanger fiddle performance data, input data acquired from the MIRAGE research project.

3.2 Hardanger Fiddle Performance Data

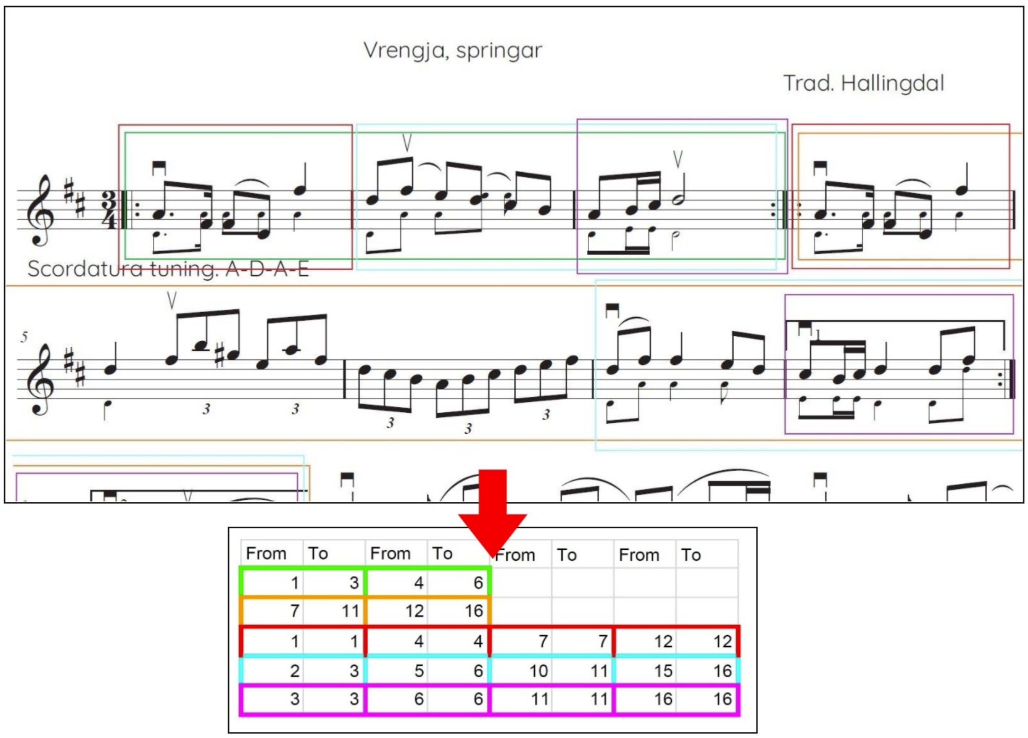
Through polyphonic pitch detection and rule-based models for automated beat tracking, MIRAGE can provide detailed Hardanger fiddle performance transcriptions with temporal and metric positions of notes. The transcriptions can be represented as spreadsheets with each row being a note event and each column being a musical feature.

Note events

onset	offset	onpitch	offpitch	essential	bar	upmeter	lowmeter	offmeter
2.03928	2.43958	72.01000	72.01000	1.00000	1.00000	1.00000	3.00000	0.00000
2.05716	2.87347	64.97000	64.97000	1.00000	1.00000	1.00000	3.00000	NaN
2.87867	3.07252	72.01000	72.01000	1.00000	1.00000	4.00000	12.00000	0.00000
2.88399	3.08035	68.84000	68.84000	1.00000	1.00000	4.00000	12.00000	NaN
3.07252	3.30261	71.96000	71.96000	1.00000	1.00000	2.00000	3.00000	0.00000
3.08035	3.19274	68.82000	68.82000	1.00000	1.00000	2.00000	3.00000	NaN
3.25333	3.58168	64.91000	64.91000	1.00000	1.00000	4.00000	6.00000	NaN
3.30261	3.56475	71.99000	71.99000	1.00000	1.00000	4.00000	6.00000	1.00000
3.56475	4.11574	72.05000	72.05000	1.00000	1.00000	3.00000	3.00000	NaN
3.57092	4.09832	80.90000	80.90000	1.00000	1.00000	3.00000	3.00000	NaN
4.10975	4.24925	76.06000	76.06000	1.00000	2.00000	1.00000	3.00000	0.00000

Figure 3.1: Excerpt from a performance transcription of "Vrengja". While the onset and offset columns specify the temporal position of note events, the upmeter and lowmeter columns (in red) represent the metric position. Performance transcription by Anders Elovsson and Olivier Lartillot.

As illustrated in Figure 3.1, the *upmeter* and *lowmeter* columns produce fractions that pinpoint the relative metric position of notes within their associated measure, such as 4/12 or 2/3. Presuming the performance is in triple meter, an *upmeter* value of 2 and a *lowmeter* value of 3 indicates a note that resides on the second beat position. However, an *upmeter* value of 4 and a *lowmeter* value of 12 indicates a note that resides on the 16th before the second beat position.



From	To	From	To	From	To	From	To
1	3	4	6				
7	11	12	16				
1	1	4	4	7	7	12	12
2	3	5	6	10	11	15	16
3	3	6	6	11	11	16	16

Figure 3.2: Excerpt of a structural representation of "Vrengja". The color-coding illustrates the correspondence between different representations (encoding) of the structural information. The "from" and "to" spreadsheet columns represent the measure-range (from measure A to measure B) of the repeating sections.

Similarly, another MIRAGE objective has been to detect repeating melodic regions, or motivic structures, in the performances. As Figure 3.2 shows, this information can also be represented in a spreadsheet format with rows corresponding to the repeating sections and columns reflecting the range of the repetitions.

Together, this temporal and structural information provides the data necessary to explore the complex rhythmical structuring in Hardanger fiddle performances with structural and multi-dimensional perspectives.

3.3 Prototype nr.1

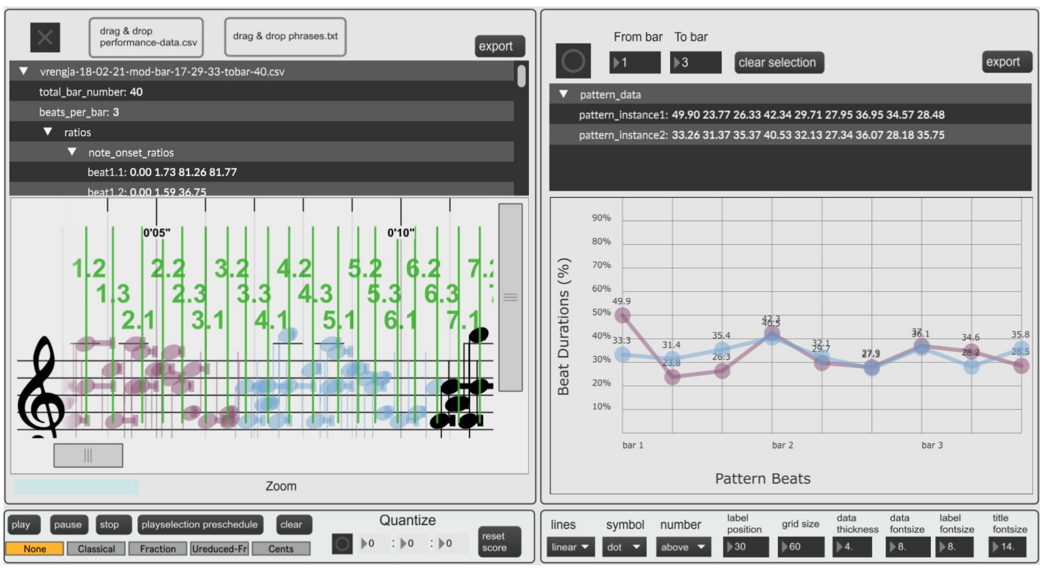


Figure 3.3: Prototype nr.1 consists of module 1 (left) and module 2 (right).

The first prototype consists of an interactive score representation (module 1) and an analytical module for investigating timing patterns of repeating melodic regions (module 2).

3.3.1 Module 1

By turning the MIRAGE performance data into something meaningful that users can engage and interact with, the first module aims to increase the data comprehension and general availability of Hardanger fiddle performance data. This module features a graphical score representation that enables users to manipulate the beat-level rhythmical structuring of performances.

Score Representation & Data Structure

The score is based on the [bach.roll] object in Max. This object enables editing, visualization and instant playback of musical scores through proportional notation where each note is prescribed a horizontal spacing equal to its rhythmic duration, as seen in Figure 3.4. The score is generated by adding lists of performance parameters, such as note onsets and durations (milliseconds), velocity (0-127) and MIDI pitches (cents), referenced from the toolkit data structure.

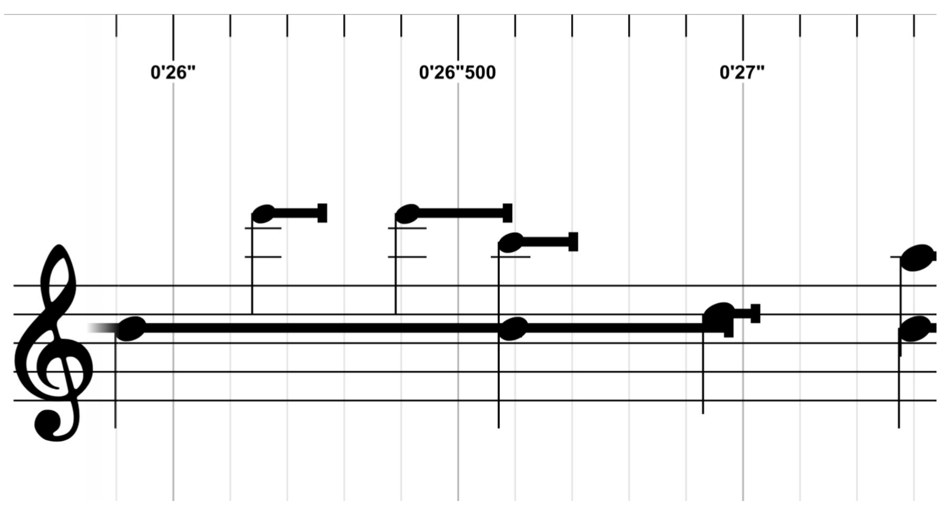


Figure 3.4: Excerpt of the [bach.roll] graphical score representation used in module 1.

When importing the Hardanger fiddle performance data into module 1, the data is first re-formatted into a dictionary data structure, as shown in Figure 3.5. As all technical operations in the prototypes reference the same data structure, this dictionary forms the basis for all module operations.

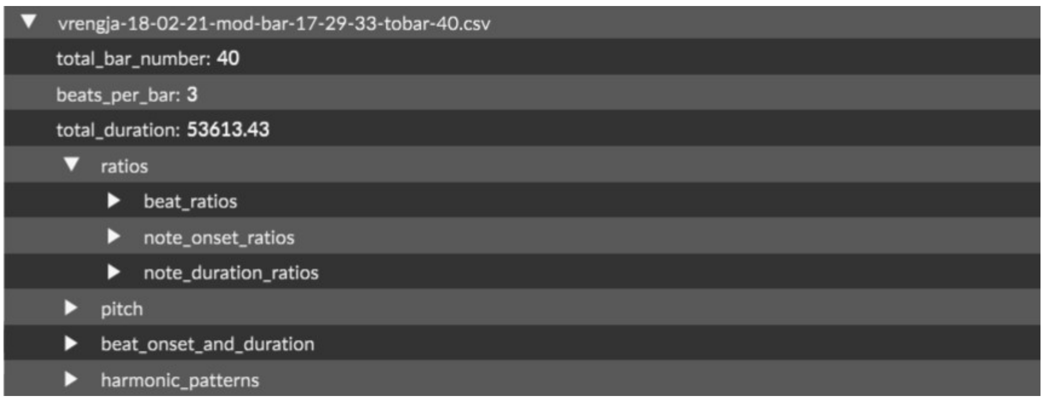


Figure 3.5: Excerpt of the data structure produced by module 1. When importing the MIRAGE performance data into the prototypes, an automatic conversion process occurs that re-organizes the data into a dictionary with custom categories.

A closer inspection of the data structure reveals that the data consists of various value and parameter types. Most parameters related to rhythm are categorized based on their position in the rhythmical hierarchy, stored as relative values such as beat and note ratios. These ratios consist of percentages that reflect the relationship between a musical event and its parent structure. For instance, note duration ratios represent note lengths (or sizes) relative to their associated beat. Similarly, beat duration ratios reflect the beat lengths (or sizes) relative to their associated measure. These relative values enable, among other features, the visual representation of the musical beats in the score representation.

Beat-level Manipulation

In module 1, the beat positions are indicated by vertical green markers, each with a unique label that identifies the bar and beat number. For instance, as shown in Figure 3.6, the green marker labeled "18.3" indicates the 3rd beat of the 18th bar.

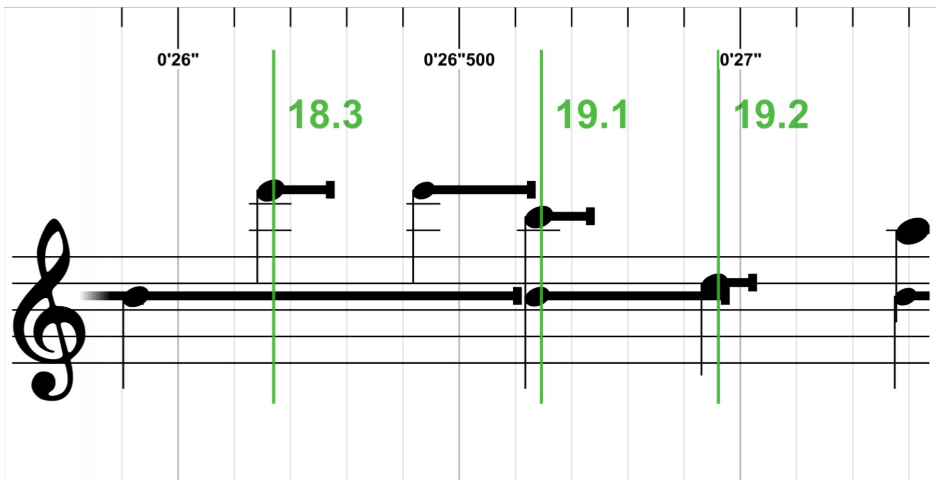
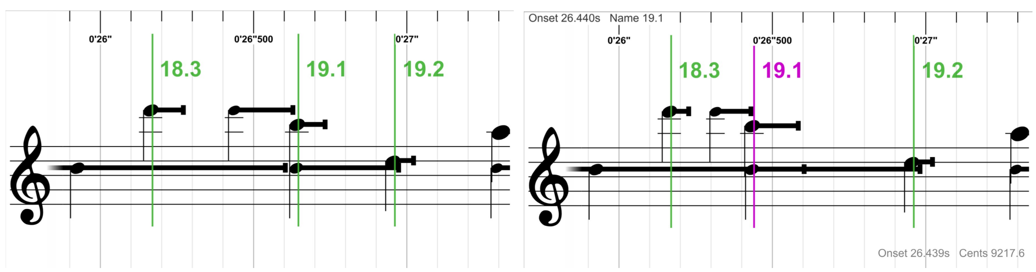


Figure 3.6: Excerpt of module 1 with green markers representing the beat positions.

The predominant interactive component of the first module is the ability to make adjustments to the beat positions. After consulting with MIRAGE about this interactive functionality, the question of how beat adjustments should affect the note positions soon became a topic of discussion. Generally speaking, it is assumed that some notes are more "responsible" for effecting beat durations in Hardanger fiddle performances than others, meaning that adjusting beat durations should ideally affect notes to varying degrees. However, a less complex solution was chosen for this implementation due to the limited scope of the thesis. When a beat position is adjusted as response to a marker displacement, all beat ratios in the data structure are updated while note ratios remain unchanged. Consequently, when the score is refreshed, all notes are scaled to maintain their relative position and duration within the beats, as illustrated in Figure 3.7.



(a) Before **(b)** After

Figure 3.7: Manually adjusting green markers re-scales note positions and durations, effectively shortening and elongating the duration of the beats.

However, a side-effect of this implementation is that neighboring beats are made longer or shorter in response to a beat adjustment. In reality, beat duration fluctuations are rarely compensated for in this manner (Johansson, 2010, p.7). Therefore, an additional feature was added, enabling beat duration compensation to be optional. To illustrate, consider the example shown in Figure 3.7 where decreasing the length of the third beat of the 18th measure increases the length of the first beat of the 19th measure. With the duration compensation option, we can leave the length of the first beat of the 19th measure unaffected by this interaction, consequently making the entire performance shorter.

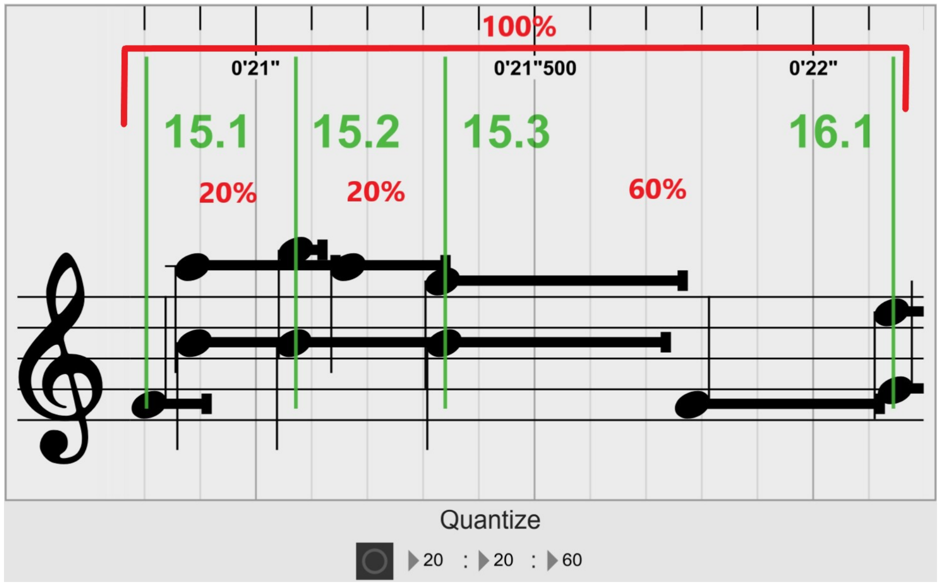


Figure 3.8: An example use-case of the quantization feature in module 1. Here, the user has manually entered 20:20:60 as a desired durational category. The score is then updated with all beat durations corresponding to this statistical relationship.

As shown in Figure 3.8, a quantization feature introduces a third and more experimental editing capability to the first module. With consideration of the durational categories often used to communicate the rhythmical structuring of different *springar* styles, as previously discussed in section 2.2.2, the quantization feature enables users to impose such categories to the entire score. The purpose of this feature is to facilitate comparisons and investigations of performances with artificially imposed durational categories.

3.3.2 Module 2

The second module features an easy-to-use analytical platform for assessing the timing patterns of motivic segments in Hardanger fiddle performances.

The module consists of a custom-built JavaScript plotting interface, designed in a [jsui] Max object, as shown in Figure 3.3.

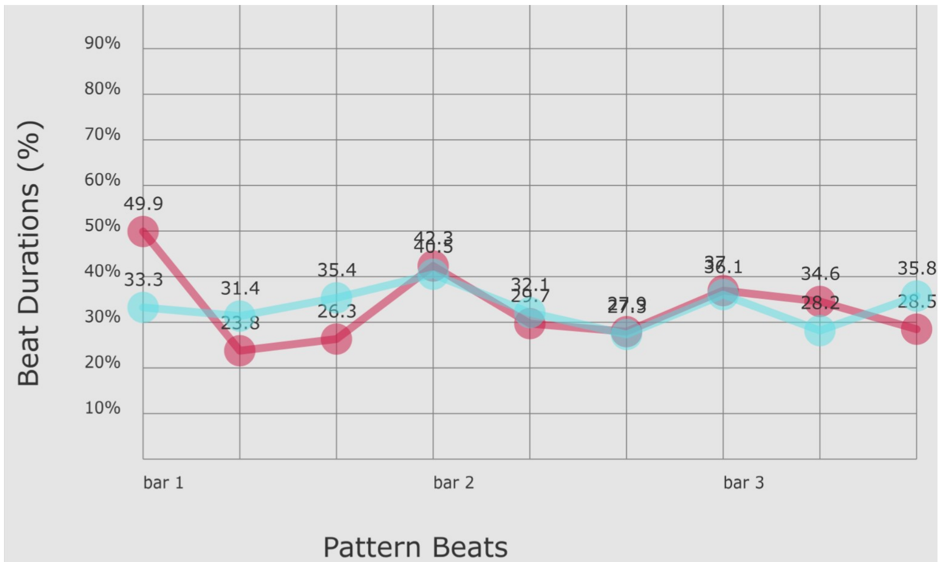


Figure 3.9: In this example, a user has requested to inspect a three-measure range in the performance. The module has identified that the user-requested range is repeated once. Therefore, the plot consists of two superimposed data entries.

Plotting Interface

Users can interact with the plotting interface by entering measure ranges (from measure A to measure B) in dedicated UI elements. The module operates by comparing the user-requests to structural data in the performance data structure. If patterns are found, i.e the range requested is subject to repetition, the module will collect the beat durations ratios from all the repeating instances and superimposes them in the plotting interface. As illustrated in Figure 3.9, the plot represents the size of patterns (number of beats) along the X-axis (width) with beat durations on the Y-axis (height).

If there are multiple data entries (repetition instances), the plot will superimpose the entries along the Z-axis (depth). Additionally, color-coding is used to visually enhance the correspondence between the plot data and note regions in module 1. When a plotting request is processed, the module generates a unique color for every data entry, colors which are immediately extended to corresponding note regions in module 1, as seen in Figure 3.10.

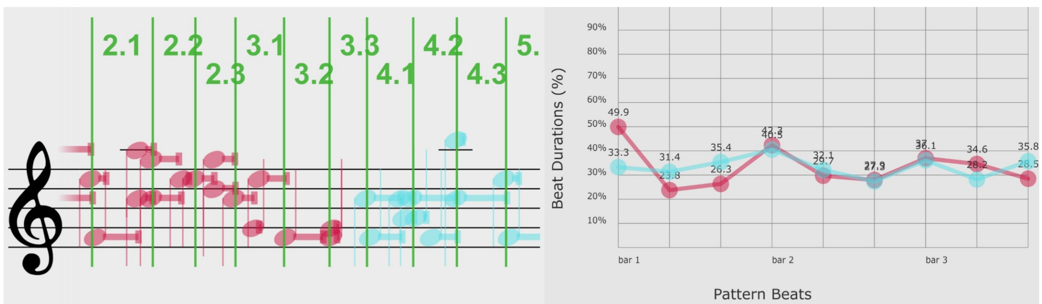


Figure 3.10: Unique color-coding is applied to both module 1 (left) and 2 (right) when plotting.

Export Options

The data structure and plotting data can be exported from the tools at any time during use. The purpose of these features is to diversify the prototypes' usability. By importing MIRAGE performance data and exporting the data structures, the tools can be used to re-structure and organize performance data for more comprehensive analysis in other environments.

3.4 Prototype nr.2

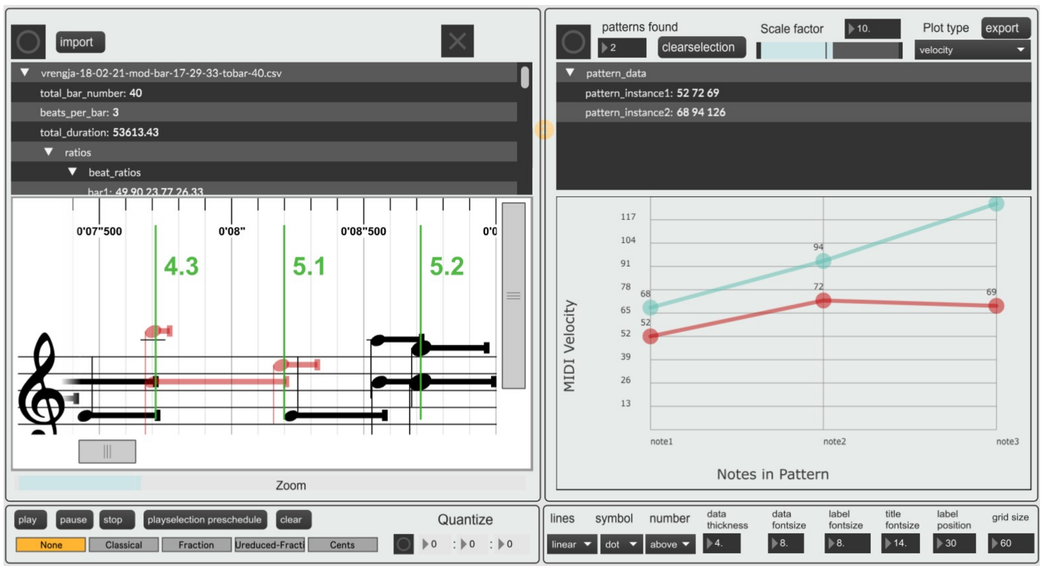


Figure 3.11: Prototype nr.2 consists of module 1 (left) and module 3 (right).

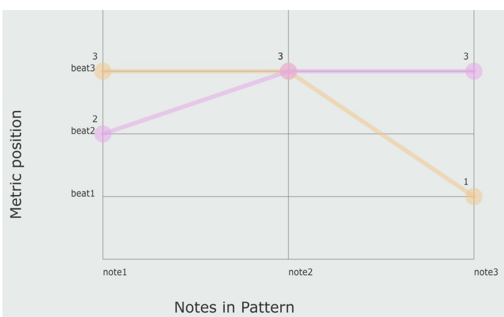
The second prototype consists of an interactive score representation (module 1) and an analytical module that explores parameter relationships between regions that share similar timing patterns (module 3).

3.4.1 Module 3

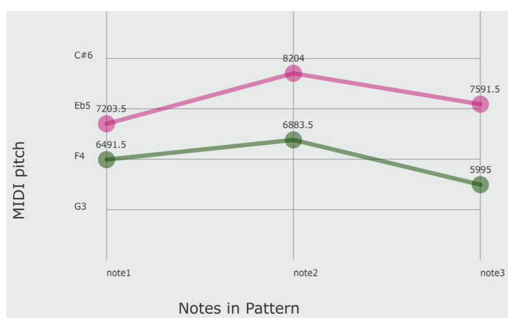
The third module features another custom-built plotting interface designed to investigate if regions with similar rhythmical properties share other parameters, such as pitch, velocity and metric position. The module 3 plotting interface is designed in a [jsui] Max object, featuring the same color-coding mechanism and export options as module 2.

Plotting Interface

Users interact with the third module by manually highlighting note regions in the interactive score (module 1) before selecting a desired parameter. The parameters available are pitch, velocity and metric position, all arbitrarily selected based on their immediate availability in the data structure for prototyping purposes. When plotting is engaged, the module collects note duration ratios from the user-selected note regions and scans the data structure for identical regions. For example, if a user-selected region consists of three notes whose duration ratios are ”40, 30, 20”, the module will scan the data structure for other note regions where a ”40, 30, 20” duration ratio pattern occurs. If similar regions are found, the selected parameter is extracted from those regions and superimposed in the plotting interface, as shown in Figure 3.12. In all instances, the plot represents the pattern size (number of notes) along the X-axis (width) with the various parameter values on the Y-axis (height), and superimposes multiple data entries along the Z-axis (depth).



(a) When investigating metric position, the Y-axis range is equal to the number of beats per bar.



(b) Frequency data (Hz) is converted into standard well-tempered notation before graphing.

Figure 3.12: Example plots in module 3 displaying metric position (a) and pitch content (b) of two note regions that share similar rhythmical properties.

Due to a limited project time frame, the pattern-finding mechanism of module 3 remained underdeveloped, lacking necessary levels of complexity. More so, by only using one simple metric (note duration ratios) to detect patterns in a dataset with high temporal accuracy, the prototype risked not being able to communicate the potential of the design concept at all. As previously discussed in section 2.1.1, automatic detection of meaningful patterns in musical performances is a challenging task often based on complex metrics, such as inter-onset-intervals (IOI), and retrieval of multiple complex features. However, in an effort to temporarily mitigate these challenges, a scaling feature was introduced, with the ability to round the duration ratios to higher numbers for easier pattern recognition. As figure 3.13 shows, the scaling feature can be used to reduce variation in the duration ratios, increasing the likelihood of finding note regions with similar duration relationships.

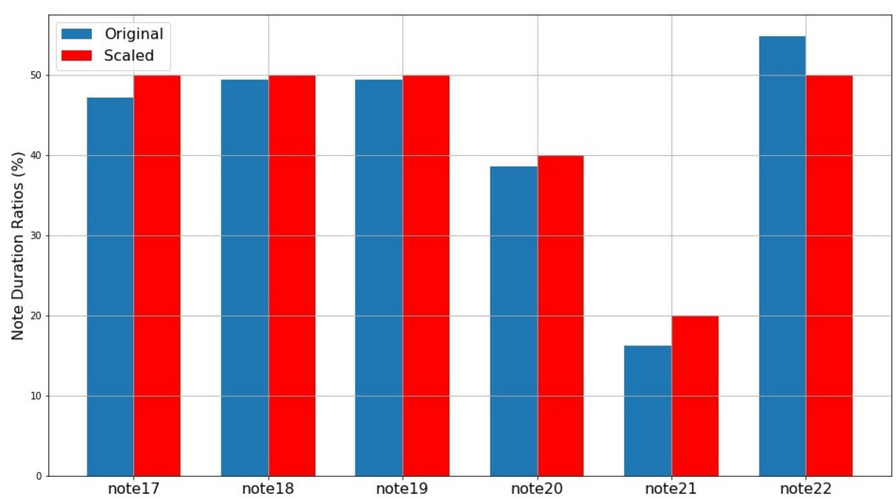


Figure 3.13: This bar chart illustrates the effect of using a scale factor of 10 in module 3. As seen, the feature can be used to effectively reduce the resolution of the note duration ratios.

3.5 Summary

This chapter presented two interactive computational tools that enable structural and multi-dimensional perspectives on the complex rhythmical structuring of Hardanger fiddle *springar* performances. Three modules were described, all designed and built based on Hardanger fiddle performance transcriptions, provided by MIRAGE, that include temporal and metric positions of notes and structural information about motivic segments in the music.

The first module consists of an interactive score representation with a unique data structure that enables several beat-level editing capabilities. Modules 2 and 3 are considered more analytical in nature, featuring custom-built plotting interfaces with several editing capabilities, color coding and various export options. The second module enables users to explore how timing patterns are related to motivic structuring while module 3 harbors the ability to investigate if regions with similar rhythmical properties (note duration ratios) share other musical parameters, such as pitch, velocity and metric position.

Chapter 4

Evaluation

This chapter presents the thesis evaluation procedure. First, the methodology is described, outlining the accuracy tests used, questionnaire design and general ethical guidelines. Second, the results are presented in chronological order, starting with the operational tests before moving on with highlights from the questionnaire responses.

4.1 Method

4.1.1 Operational Tests

The prototypes consist of two analytical modules used to detect structural and multi-dimensional relationships in Hardanger fiddle performances. Therefore, a set of operational tests were designed to assess the technical accuracy and general usability of these modules, in particular. The tests used a quantitative and comparative approach to assess these criteria, influenced by dialog with experts affiliated with the MIRAGE research project and contemporary research. First, a known hypothesis about the rhythmical structuring of Hardanger fiddle *springar* performances was examined using module 2, assessing whether the module results were consistent with contemporary research. Second, musical notation was used as a reference point to assess the pattern-finding mechanism of module 3.

Test 1

The first test investigated whether data produced by module 2 was consistent with contemporary performance studies, suggesting that beat duration variations in *springar* performances are related to motivic structuring, as previously discussed in section 2.2.2. The test was conducted on four different interpretations of "Godværsdagen", a *Halling-springar* with a nominal "short-long-average" durational category, performed and annotated by Olav L. Mjelva with transcriptions and structural data from Oliver Lartillot and Anders Elowsson. After further discussion with Olav, and inspection of the score material, a handful of prominent motifs were identified. As result, six motifs were chosen for the experiment, all repeated between 2 and 10 times in the music, among which both two and four-measure motifs were considered.

First, all six motifs in each performance were identified in module 2 where their timing patterns were exported in concise dictionary formats. Then, the dictionaries were used to calculate the standard deviation (SD) over the duration of each beat positions within the motifs separately, as illustrated in Figure 4.1. The output of this calculation left one metric per beat per motif. Finally, the averages of these values were taken, leaving one metric per motif, indicating the amount of beat duration variation per motif[1].

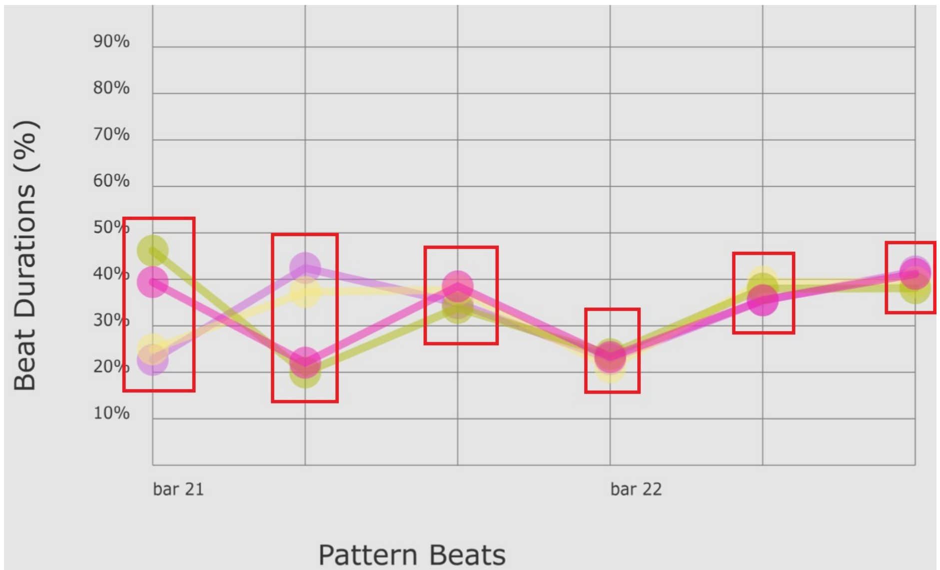


Figure 4.1: By calculating the standard deviation over the duration of every beat index (the collections of beats colored in red), we can make a quantitative assessment of how much beat duration variation there is across repeating melodic sections.

As reference points, control structures were created that enabled comparisons between performances, as a whole, and their motivic components. The control structures were comprised of all beat duration ratios in a performance arranged according to their associated measure, data that was accessed by exporting the data structure of each performance in module 2. Considering that each performance in the experiment was 98 measures long in triple meter (3/4), each control structure consisted of 98 instances, where every instance was 3 beats long. With this approach, the same SD operations conducted on the motifs could be utilized on the performances themselves, leaving one

[1]Test 1 Python notebook in Appendix B.1

metric per performance, indicating the amount of beat duration variation per performance. The main advantage of this experiment design was that it compensated for the durational categories and complex rhythmical structuring within each measure by assessing the deviation across beat positions. Therefore, by comparing the SD metrics of the motifs to their associated control structure, a precise evaluation could be made of whether variations in timing patterns were influenced by motivic structuring, or not.

Test 2

The second experiment explored a more alternative use-case scenario to gain insight into the usability of module 3, investigating whether the current system implementation[2] was capable of identifying symbolic rhythmical patterns in the music. The symbolic rhythms in question refer to rhythmical figures in the musical notation, consisting of collections of note-events. A symbolic rhythmical pattern occurs when a particular rhythmical figure is repeated in the notation, as exemplified in Figure 4.2. By locating the position of several such patterns, a test could be formulated, assessing if module 3 could identify repeating occurrences of symbolic rhythmical patterns in a performance that were referenced from notation.

[2]The pattern-finding mechanism of Module 3 is described in section 3.4.1.

Figure 4.2: Notation excerpt of "Vrengja". The red sections highlight a simple rhythmical pattern (eight-note triplet) that is repeated 4 times (or more) in the music.

The experiment was conducted on one performance of "Vrengja", a *Halling-springar* with a nominal "short-long-average" durational category, performed and annotated by Olav L. Mjelva with transcriptions and structural data from Oliver Lartillot and Anders Elowsson. Five basic rhythmical patterns were identified in the notation, consisting of either individual eighth-note or eighth-note triplet figures. Then, corresponding note regions in the interactive score (module 1) were located and used as input for module 3. The scaling feature was used throughout testing in an attempt to mitigate the experiment's underlying and uncertain assumption that repeating rhythmical figures in the notation are usually performed with similar note duration ratios. Therefore, each sequence was processed multiple times, each time with a different scale factor. Finally, results were compared and cross-referenced.

4.1.2 Questionnaire Design

The questionnaire was designed to collect systematic feedback on more aesthetic and conceptual aspects of the modules. In essence, the questionnaire addressed the claim that there is a need for more interactive computational tools in traditional Scandinavian folk music research and queried whether the proposed toolkit possessed the capabilities to satisfy some of these demands, and if so, how they managed to do it. In an effort to increase the quality of the questionnaire responses, a short online presentation that provided a comprehensive overview of the toolkit was given to all participants directly beforehand. The questionnaire featured fourteen questions split into four sections, each with a central theme to enable a more categorical approach (Krosnick, 2018).

- 1. Personal (Appendix A.1-2 and A.1-3)

The first section categorized the participants' background and relation to Scandinavian folk music. The questions mapped the occupational demographic of the attendees, how familiar they were with traditional folk music research and if they performed Hardanger fiddle music or not. The response provided insight into the prototypes' reception by participants with different use-case intentions. However, due to ethical considerations, these questions remained optional.

- 2. Interactive tools in research (Appendix A.1-3 and A.1-4)

The second section investigated whether there is a demand for tailored interactive computational tools in traditional Scandinavian folk music research, examining the core premise of the research question. These questions inquired whether the participants have ever felt the need for more tailored interactive tools in their professional careers, and if they believed such tools can contribute to Hardanger fiddle performance studies, in particular.

- 3. Toolkit design (Appendix A.1-5, A.1-6 and A.1-7)

The third section assessed the conceptual approach, general functionality and user experience of the tools. These questions sought to pinpoint design weaknesses by measuring the prototypes' prospects of increasing our understanding of Hardanger fiddle performance patterns. This section also investigated to what degree the specific data visualization techniques increased the accessibility of the performance data and whether increased accessibility, in this context, is scientifically beneficial.

- 4. Alternative approaches and other feedback (Appendix A.1-7 and A.1-8)

The last section sought to gain knowledge about how the tools could be improved by opening for un-restricted feedback and suggestions from participants. This response was valuable for the critical assessment of the prototypes.

Participant Selection

The invitation to join the online presentation was primarily extended to all personnel affiliated with the MIRAGE research project, consisting predominantly of expert musicologists, Hardanger fiddle performers, library scientists, cognitive researchers and computer scientists. This occupational demographic was prioritized due to the precise scientific and performance-oriented theme of the study. However, participation was not restricted as invitations were extended to all music-related researchers at the RITMO research center, music students at the University of Oslo and others interested in partaking.

4.1.3 Ethical Guidelines

The study's technical development is considered open-source material meaning the code-base remains publically available through online services. A selection of modified performance data was included in the download versions of the prototypes for testing purposes. This performance data was approved by the MIRAGE team before the prototypes were made available, following standard GDPR conduct and UiO's ethical regulations. No further data protection was required as no personal data was collected in the questionnaire, other than optional occupation, and no media record exists of the online presentation. The questionnaire was implemented in a Google form[3] due to its efficiency structure and user-friendliness, while other feedback reached the author through either email or the GitHub development platform[4].

[3] https://www.google.com/forms

[4] https://github.com/AleksanderTidemann/hardanger-fiddle-performance-analysis

4.2 Results

4.2.1 Operational Results

Results from the first operational test proved that the data produced by module 2 was consistent with contemporary Hardanger fiddle performance studies, suggesting that beat duration variations in *springar* performances are influenced by motivic structuring. As shown in Table 4.1, a significant drop in timing pattern variation is identified when the data was re-arranged following the motifs. On average, motifs displayed 60% less deviation to their beat durations when compared to their associated control structure. It was also evident that there was no correspondence between the number of repetitions to a motivic segments and its beat duration variation.

"Godværsdagen" Halling-springar	Performance 1	Performance 2	Performance 3	Performance 4
Motif 1 Two-measure motif with 10 repetitions	1.276	1.178	1.963	3.396
Motif 2 Two-measure motif with 6 repetitions	1.079	1.003	1.705	2.530
Motif 3 Four-measure motif with 2 repetitions	0.856	1.062	2.015	2.429
Motif 4 Four-measure motif with 6 repetitions	2.286	1.217	1.936	1.979
Motif 5 Two-measure motif with 4 repetitions	0.760	1.390	1.345	2.111
Motif 6 Two-measure motif with 4 repetitions	1.257	0.526	1.913	1.882
Mean	**1.25**	**1.06**	**1.81**	**2.38**
Control Structure Single measure with 98 repetitions	**5.525**	**5.121**	**6.31**	**6.118**

Table 4.1: Standard deviation of timing patterns of six motivic segments in four different interpretations of *Godværsdagen*, together with control structures. Performances by Olav L. Mjelva.

The second experiment showed that module 3 rarely managed to identify repeating rhythmical patterns referenced from the musical notation. Of the five patterns tested, only three were partly detected by the system, as illustrated in Figure 4.3. Furthermore, no attempts were successful without utilizing a scale factor of 10 or more. This is unfortunate as a high scaling factor reduces the nuance and resolution of the music. It was also evident that increasing the number of notes in a pattern required a corresponding increase in scale factor.

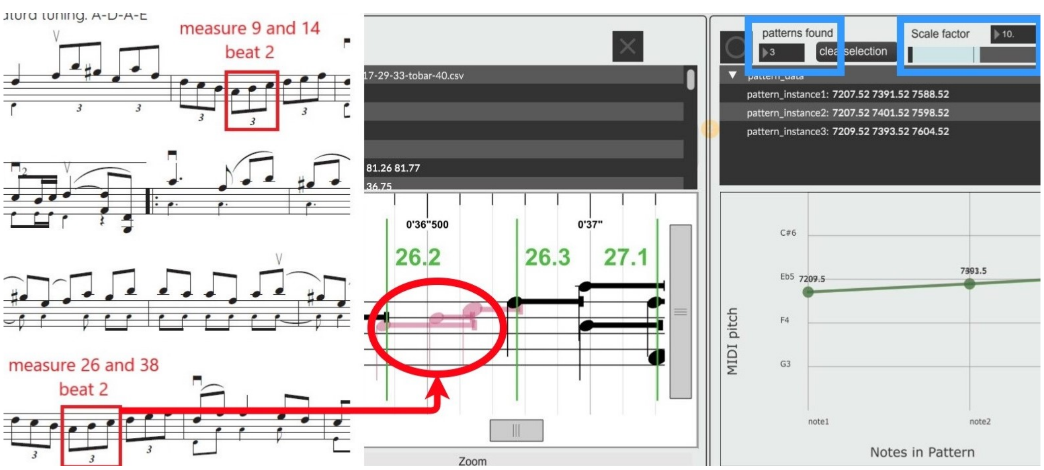


Figure 4.3: With a high scale factor, simple rhythmic patterns in the musical notation (left) could be detected in the performance (right). The illustration shows that 75% of a recurring triplet figure was successfully detected in module 3, only with a scale factor of 10.

4.2.2 Questionnaire Results

The questionnaire was administered on March 4th, 2021, directly following an in-depth online presentation on the prototypes and their functionalities.

Although participation was limited to 4 people, all attendees completed the survey in one sitting.

Parts 1 & 2 - Personalia & Interactive Computational Tools in Research

Results from part 1 showed that all attendees had a music-related background and that 50% were experienced Hardanger fiddle performers (Appendix A.2-1 and A.2-2). Additionally, 50% of the participants said they had traditional music as their primary field of research, meaning the overall majority processed a high familiarity with traditional Norwegian folk music.

The response in part 2 suggests that there is a demand for more tailored technologies in traditional Scandinavian folk music studies and that such technologies can contribute to our understanding of Hardanger fiddle performance patterns (Appendix A.2-3). Further, the response showed that a majority of participants were positive about the prospect of using the tools for research purposes, indicating that the proposed toolkit has the potential to accommodate some of these demands.

Part 3 - Toolkit Design

In part 3, the response indicated that structural and multi-dimensional perspectives are desirable components in interactive computational tools that explore Hardanger fiddle performance patterns (Appendix A.2-4 and A.2-5). The results show a particular interest in the multi-dimensional analysis approach of module 3, a notion further highlighted by additional feedback received in part 4. Further response indicated that the various visualization techniques were successful in increasing the accessibility of the performance data and that this effect is considered beneficial to research on musical performance patterns.

Part 4 - Additional feedback

In part 4, the written responses showed that 50% of attendees specifically advocated for multi-dimensional perspectives, features that enable investigation of relationships between musical parameters and practices.

> Responses to question 12, part 1 (Appendix A.2-7):
>
> - *"Tempo meter and pitch"*
> - *"Multiple input sources: tapping, accelerometer, video"*

Further responses underlined other desirable features for tailored technologies that explore musical performances, such as more advanced export options, data formatting standards and cross-compatibility.

> Responses to question 12, part 2 (Appendix A.2-7):
>
> - *"I think to be able to record something and get sheet music as exactly as possible is a huge step forward"*
> - *"Ease of import/export data in standard format (easy to integrate with other tools)"*

Also, suggestions were made recommending that further development could benefit from a web implementation, i.e removing the dependency from the Max programming environment, and an extended scope including larger corpora of music rather than individual performances.

> Responses to question 14, (Appendix A.2-8):
>
> - *"The prototype in max is great, and within the scope of the thesis this is probably the only feasible path. But to benefit the community at large, this should be a standalone application non depending on max (perhaps something that runs in the browser!).*
> - *"My main interest is here what could be used on individual recordings and what could be used on large corpora and analyzed statistically."*

4.3 Summary

In summary, the thesis evaluation featured a combination of qualitative and quantitative methods. First, two operational tests assessed the operational accuracy and general usability of modules 2 and 3, measuring whether the module results were consistent with contemporary performance studies and symbolic representations of the music. The results from the first test proved that module 2 was capable of producing data in support of recent research, indicating the conservation of timing profiles throughout occurrences of motivic patterns in Hardanger fiddle performances. Conversely, the second experiment showed that the pattern-finding mechanism of module 3 rarely identified symbolic rhythmical patterns from the musical notation without utilizing a high scale factor.

Second, a questionnaire was administered directly following an online presentation, held on March 4th, 2021, to 4 participants. The questionnaire featured fourteen questions designed to collect systematic feedback on more aesthetic and conceptual aspects of the prototypes. The response showed a particular preference for the multi-dimensional analysis approach of module 3 and features that promote cross-compatibility, multiple import/export options, and consistent data standards. Furthermore, a clear majority of participants agreed that there is a demand for more tailored technologies in in research related to Scandinavian folk music and that such technologies can contribute to our understanding of Hardanger fiddle performance patterns. Other interesting findings indicated that increasing the accessibility of the performance data through visualizations can be particularly effective in this regard.

Chapter 5

Discussion

The evaluation process successfully generated valuable data identifying pros and cons in the prototypes' design and development approach. However, the question remains how to interpret these results within the relevant contexts. This chapter uses the results as basis for a discussion, providing some critical nuance and perspective on the methodological framework and the toolkit design.

5.1 Methodological Approach

Using a combination of qualitative and quantitative evaluation approaches helped diversify the response, making it easier to identify general tendencies in a limited research period and participation. Although not a method of evaluation, per se, the most valuable qualitative feedback was attained through having constant dialog with experts affiliated with MIRAGE. This computational and musicological expertise influenced the general approach, development, and evaluation procedure, significantly improving and shaping the project in most essential ways.

On the other hand, the quantitative basis for the study had some clear limitations. With only four subjects completing the questionnaire, none of the survey results can be considered statistically significant. It is also worth considering how the structure of the evaluation could have influenced the questionnaire results. For instance, the presentation leading up to the questionnaire might have affected the response in part 2, querying whether there is a demand for more tailored technologies in musicological research contexts. In this case, the presentation might have established the very demand the questionnaire was seeking answers to, a known phenomenon in questionnaire design procedures (Krosnick, 2018, p.450). Similarly, the operational tests are prone to bias through the author's design. Although both tests provided some basic assessments of the modules, shedding light on the general functionality and prospects of the prototypes, their margin of error is likely to be high due to the small sample sizes used.

These methodological limitations directly affect how the results of the study should be interpreted and understood. In the author's opinion, the results should be interpreted more as valuable feedback, and guidance towards further development, than scientifically definitive. In this regard, it is legitimate to forward critique of the methodological framework itself, in the sense that it might have sacrificed quality over quantity. By utilizing fewer evaluation methods, such as *only* an in-depth questionnaire, it is possible that the evaluation results could have been considered more scientifically valid.

5.2 Toolkit Architecture & Interactive Design

The questionnaire results indicated that the interactive score (module 1) can contribute to our understanding of Hardanger fiddle performance patterns by increasing the accessibility of the performance data. If we further consider the response to questions 6, 10 and 11[1] in this context, it is reasonable to suggest that the willingness of participants to use the prototypes might be largely attributed to these interactive and visual techniques, in particular. However, although most of the interactive visual features were contained in module 1, the plotting interfaces of modules 2 and 3 were a considerable part of the aesthetical design of the prototypes, enabling a different visual representation of the musical data.

On a related note, bringing together dedicated tools for analysis (modules 2 and 3) and data manipulation (module 1) raises some valid questions about the toolkit architecture. Being able to manipulate data can affect the validity of analytical systems and their results. Although legitimate concerns, there are use-cases where such unique capabilities might be beneficial. For instance, exploring alternative timing profiles in performances can benefit from additional visual cues. In such cases, the analytical modules would serve more as a visual aid, enhancing the data representation for editing purposes. However, little evidence is provided in support of these proposed utilities as it remains unclear whether the ability to manipulate beat-level rhythmical structures of performances has any real benefit to performers,

[1] Appendix A.2-4 and A.2-6

researchers, or music tutors.

Generally, the lack of good data on the user experience of module 1 remains a limiting factor of the study. As result, the thesis only manages to pinpoint that there is a potential for interactive tools to benefit research and our understanding of performance patterns. Precisely how the interactive design or visualization techniques in question provide these benefits, remains unclear. An ideal evaluation setting would consist of a questionnaire administered after longer periods of user-testing, preferably in various educational settings, facilitating a more in-depth study of the effect of the module over time.

5.3 Usability & Structural Perspectives

The ability to associate musical parameters with parent structural components seems to be a step towards a more comprehensive understanding of the mechanics of and behind performances. According to the questionnaire, the structural perspectives and design proposed in module 2 have real prospects of contributing in this regard. Also, as anticipated in section 3.3.2, it was evident that having consistent data standards, multiple import/export options and a well-organized data structure helped diversify the functionality and usability of the modules, making the tools more versatile and compatible with other computational environments. These aspects further gained the author's support when using the prototypes' data structures to conduct the operational tests.

The first operational test was designed to explore the technical and analytical capabilities of module 2. While the test successfully showed that variations in timing patterns are influenced by motivic structuring, the question remains how we should interpret these results within the context of the thesis. Generally speaking, *springar* performances do not contain substantial variation in their asymmetrical timing patterns by default. Sometimes there is a lot, and sometimes there is very little. What the research is suggesting is that we should try to interpret these variations as a product of the "melodic-rhythmic" architecture and structural contexts. In other words, what the performer is "saying", melodic-rhythmically speaking, can often manifest itself in beat duration variations. However, to fully adopt such a structural perspective implies that we should also acknowledge how other factors, such as bowing patterns, ornamentation, and dance movements, directly influence the unfolding and shaping of the musical content. In this case, we see that structural analysis requires us to consider a larger range of variables, which, in turn, increases the complexity of the interpretation process.

When reflecting on these aspects, it is evident that although the operational test was successful, proving that the module behaved as expected, the output was not very meaningful by itself. In other words, the actual capabilities of module 2 are quite limited. In the author's opinion, for module 2 to successfully increase our understanding of Hardanger fiddle performance patterns, it should, ideally, include features that further help to guide the interpretation process. For instance, in an educational setting, we can imagine how much more useful module 2 would be if it offered integrated methods for calculating variability metrics or AI that automatically detected correlations across a multitude of musical dimensions.

5.4 Multi-dimensional Perspectives & Pattern Detection

It was evident by the questionnaire responses that the ability to examine relationships between musical parameters and practices was the most successful toolkit design concept, further supporting the notion that Hardanger fiddle performance patterns are interdependent on a range of musical dimensions. Additionally, with the written feedback advocating for other multi-dimensional analysis capabilities, it seems that the module successfully communicated the potential of such tailored technologies.

At the same time, the second operational test was able to provide some critical insight into the technical design, ultimately addressed whether the current pattern-finding implementation strategy would ever be capable of producing meaningful results without referring to symbolic or structural layers. As previously discussed in section 2.1.1, most contemporary music research related to the development of complex analysis frameworks advocate for implementation strategies that consider a range of musicological contexts, perspectives that have to address the intricate relationships between low-level descriptors and structural layers of music. Although the second operational test was not particularly well-equipped to provide any further insight into these matters, it was successful in its ability to accentuate weaknesses and strengths in the module's design, highlighting the potential benefits of such complex capabilities to research and educational tools. With this in mind, it is in the author's opinion that an ideal implementation of module 3 should be built on existing frameworks and retrieval systems, preferably integrated into a software environment more advanced and cross-compatible than Max, such as a web application.

However, tools with multi-dimensional perspectives on musical performance patterns do not necessarily have to include complex pattern detection. In fact, most of the written responses and feedback advocated for alternative approaches, such as how bowing patterns are related to the melodic content or how foot-stomping is related to the beat positions. This response was not unexpected considering that both performance studies on traditional Scandinavian folk music and MPA are specifically interested in the link between musical practices and performance parameters. In practice, modifications to module 3 could easily have been made to support more input sources and comparisons via manual selection instead of automatic pattern detection.

Chapter 6

Conclusion

Analyzing musical performances is a challenging and emergent field of computational music research, aiming to reveal performance patterns and link them to musical contexts. The MIRAGE research project is currently contributing to this scientific body, addressing the modest amount of research on Scandinavian folk music and the ongoing demand for more precise computational frameworks that increase our understanding of the mechanics behind musical performances, utilizing a transdisciplinary research approach that builds on contemporary musicological perspectives. A way to mitigate challenges inherent to transdisciplinary research approaches is to develop tailored technologies that seek to increase the availability of expertise and knowledge across disciplines. The need for better research and educational tools for assessing musical performances has also been addressed by recent MPA research. By focusing on how we can design interactive computational tools to explore Hardanger fiddle performance patterns, this thesis has aimed to increase the availability of computational music research in the field of musicology, offering small contributions to music research, Scandinavian folk music studies, and to the preservation and modernization of valuable cultural and national heritage.

To address the research question, a toolkit has been proposed, consisting of two software prototypes with three modules, enabling structural and multi-dimensional perspectives on the complex rhythmical structuring of Hardanger fiddle *springar* performances through interactive user-interfaces. The approach was motivated by the current capabilities of MIRAGE and contemporary research showing that beat-level timing variations in *springar* performances seem to be related to "melodic-rhythmic" structures, supporting the notion that the rhythmical structuring of Hardanger fiddle performances is interdependent on a range of musical dimensions and practices. The system evaluation featured a combination of qualitative and quantitative approaches. First, two simple operational tests assessed the technical and operational accuracy of the modules. Second, a questionnaire was administered, designed to collect systematic feedback on more aesthetic and conceptual aspects of the prototypes.

Upon reflecting on the evaluation results in the context of the primary thesis objective, a number of key findings were identified. First, there seems to be a demand for more tailored software tools in the field of musicology and Scandinavian folk music research. Moreover, the results suggest that the proposed toolkit has the potential to contribute to our understanding of Hardanger fiddle performance patterns, meaning it has the ability to accommodate for some of these demands. Second, when developing such tailored technologies, we should not underestimate the significance of interactive features and other aesthetic factors. Although the precise contribution of the interactive and visual design in the current prototypes remains unclear, it is evident that these factors increased the accessibility of the performance data, an effect considered beneficial to research on musical performance patterns. Third, for such tools to be relevant in contemporary research and educational contexts, they should be capable of examining the interrelations between musical dimensions, preferably how musical practices, such as bowing patterns or foot-stomping, impact various musical parameters and structural components, and vice versa. Evidence also suggests that integrating existing computational analysis frameworks and retrieval systems could offer further benefits in these cases, increasing the overall prospects of the tools by improving their technical accuracy and general compatibility. Fourth and final, in order to tailor to an audience with varying degrees of musical or technical expertise, tools with the proposed levels of complexity should, ideally, include features that further help guide the interpretation process. When linking performance parameters to various structural and symbolic layers, the number of variables in our analysis increases, rendering it more complex to make precise interpretations. Therefore, if we seek to design tools that increase the availability of music research in the field of musicology and the general public, we should also consider how to facilitate a better and more nuanced interpretation of the output from said tools.

6.1 Limitations & Further Research

With limited prior knowledge of CMA and Scandinavian folk music studies, the core challenge of this thesis project was to develop an approach that was in alignment with the current goals and objectives of the MIRAGE research project. With only one semester to complete the study, these challenges were further amplified, leading to several technical and methodological compromises along the way. In an effort to mitigate these challenges, a combination of approaches was used to diversify the evaluation procedure, anticipating that this would make it easier to identify general tendencies in a limited research period and participation. However, as result, the scientific validity of the project was affected.

Optimally, future development should see a software migration from Max to a web application. A web application is easier to use, more maintainable, has better support for interactive and UI design elements, and facilitates more complex functionality. More importantly, a web solution would render the application to be more compatible with other software. A software migration would also invite the opportunity to upgrade and refine the toolkit features and general functionalities. Although the findings suggest that future development should priorities features that enable more multi-dimensional perspectives, it would also be worth examining how the complexity of the performance data could contribute to more advanced interactive features and general usability. For instance, it would be interesting to explore how the structural data could help make the beat adjustments more meaningful and structurally consistent. A working prototype of such a feature was already developed in the project period, detecting if an adjusted beat was part of a motif. If so, the system propagated the local beat adjustments to all motivic instances.

Finally, having more carefully designed features in a web-based solution could enable a better evaluation procedure with the ability to collect more varied data and reach more people in a shorter period of time. For instance, it would be interesting to conduct systematic user-testing of module 1 in various educational settings over long periods. Various types of user data could be collected through the web-based platform, providing a more in-depth evaluation of the module's prospects of becoming a reliable tool for musical performance assessment. Also, with an updated system architectures, it would be possible to explore whether the data formatting capabilities could assist in the creation of larger datasets for predictive models and other AI music-related technologies.

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Appendix A

Questionnaire

A.1 Design

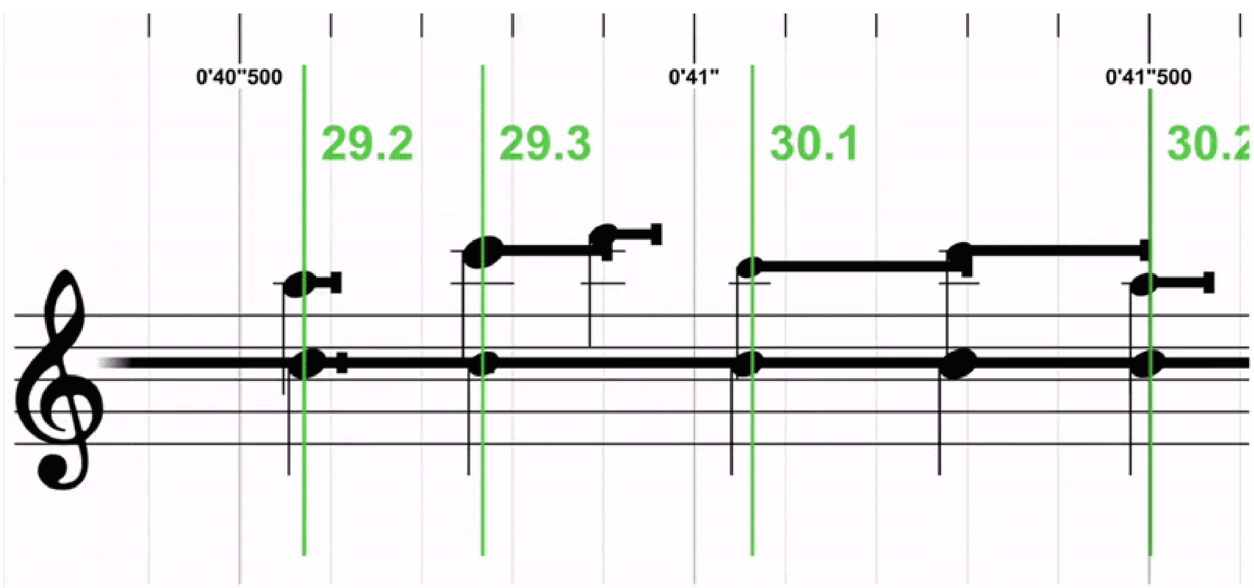
Interactive Tools for Exploring Performance Patterns in Hardanger Fiddle Music

Welcome to this questionnaire in response to Aleksander Tidemann's presentation on interactive computational tools for exploring performance patterns in Hardanger fiddle music. The questionnaire consists of 4 parts, 14 questions in total, and should take no longer than 5 - 7 minutes to complete.

Part 1 - Who Are You?
Part 2 - Interactive Tools in Research
Part 3 - Toolkit Design
Part 4 - Alternative Approaches and Other Feedback

Source code and additional documentation:
- https://github.com/AleksanderTidemann/hf-interactive-analysis

Try the tools for yourself:
- https://github.com/AleksanderTidemann/hf-interactive-analysis/releases/tag/V1.0-beta



Brief Description / Recap

The prototyped tools are designed to examine performance patterns in traditional Norwegian folk music, specifically focusing on timing patterns (performance timing) in Hardanger fiddle performances. I propose a set of interactive tools that examine these characteristics in the following manner:

1. In the first tool, an interactive and adjustable score representation enables dynamic editing of the performance timing. Additionally, a custom plotting window enables us to inspect timing patterns of repeating sections and phrases.

2. In the second tool, we can investigate the musical properties of recurring timing patterns. By selecting a note region in the score representation, the program will find other regions that exhibit similar timing patterns. Then, plotting helps us examine whether these recurring timing patterns share other musical properties, such as pitch, metrical position and/or dynamics.

Who are you?

This questionnaire does not collect any personal data. However, I would like to know if you're a researcher in the field of musicology and how familiar you are with the study of Scandinavian folk music.

1. 1. What do you consider your primary field of research? (multiple choice)

Markér bare én oval.

- Computer science
- Traditional/folk music
- Rhythm, time and motion
- Music theory and/or composition
- Music cognition and/or psychology
- Other musicology related research
- Other
- Student
- I prefer not to answer

2. 2. How familiar are you with the research and study of traditional Norwegian folk music?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

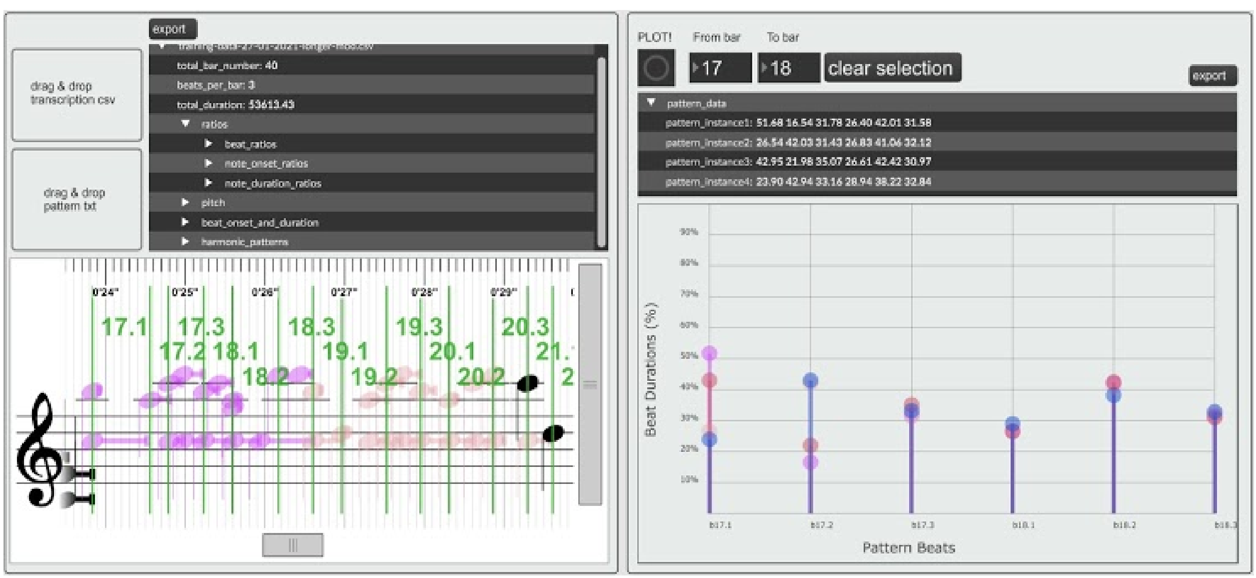
3. 3. Do you perform or play Hardanger fiddle?

Markér bare én oval.

- ◯ Yes
- ◯ Occasionally
- ◯ No

Interactive Tools in Research

The aim of this part is to get a brief insight into the demand for interactive computational tools in musicology-related research.



4. 4. In your professional career, have you ever felt the need for more personalized software tools for data management, pattern recognition or other research purposes?

Markér bare én oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much so

5. 5. To what degree do you think interactive computational tools can contribute to Hardanger fiddle performance studies?

Markér bare én oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much so

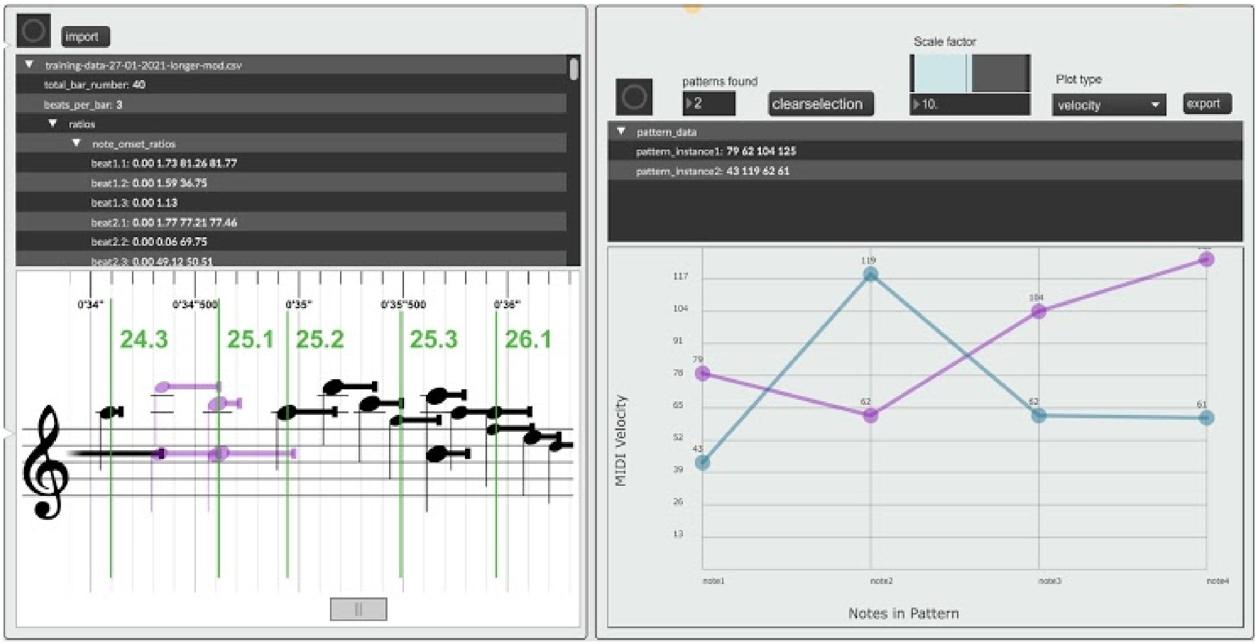
6. 6. Would you consider using any of the presented tools for your own research and/or explorative purposes?

Markér bare én oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much so

Toolkit Design

The aim of this part is to gain valuable feedback on the approach I have taken when designing the 2 prototyped tools for my thesis; exploring timing patterns of Hardanger fiddle performances.



Tool nr.1 - Interactivity and engagement

7. 7. The first tool has the ability to dynamically adjust beat position through an interactive interface. Do you think this feature could give players and researchers a better understanding of the asymmetrical timing patterns in Hardanger fiddle performances?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

Tool nr.1 - A structural perspective

8. 8. The first tool also has the ability to explore timing patterns of repeating sections and phrases. Do you think this feature could contribute to our understanding of performance patterns in Hardanger fiddle music?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

Tool nr.2 - Multi-dimensional analysis

9. 9. The second tool has the ability to compare various properties of repeating timing patterns, for instance if regions with similar timing patterns share similar intensity, motivic/beat position and/or pitch content. Do you think this feature could contribute to our understanding of performance patterns in Hardanger fiddle music?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

User Experience

10. 10. The tools utilize various data visualization techniques, such as a unique score representation, coloring and dynamic plotting capabilities. Would you say these techniques increased the accessibility of the computational performance data?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

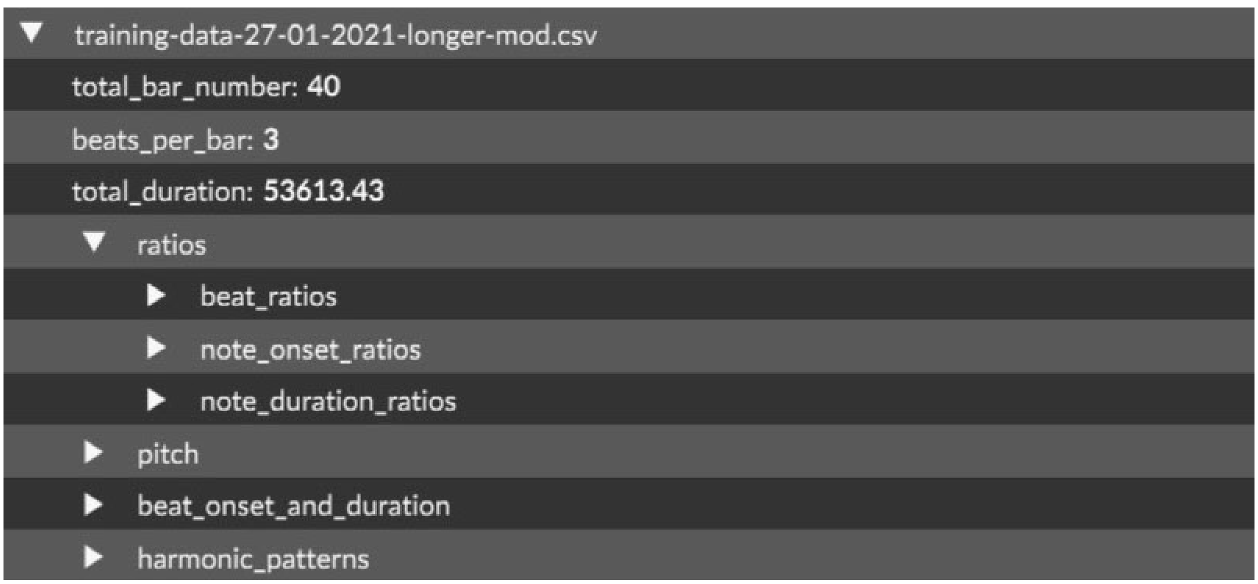
11. 11. Do you think that research on musical performance patterns can benefit from improved data visualization techniques?

Markér bare én oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much so

Alternative Approaches and Other Feedback

We are almost done! In this last part, I hope to gain valuable feedback on alternative design approaches to designing tools for exploring musical performance patterns.



12. 12. Imagine you were to acquire some personalized interactive software tools designed to contribute to your study or exploration of musical performance patterns. Please list a few features that you would like the tools to have.

13. 13. Would you prefer your imagined set of personalized tools to be "modular" (a set of smaller tools) or singular (one "all-encompassing" tool)?

Markér bare én oval.

- I think a modular design would be best
- Neutral
- I'd like to have everything in one place

14. 14. If you have more thoughts and/or feedback on matters relating to specific questions in the questionnaire, or just in general, please elaborate a sentence or two here. (Optional)

A.2 Results

Interactive Tools for Exploring Performance Patterns in Hardanger Fiddle Music

4 svar

Publiser analytics

Brief Description / Recap

Who are you?

1. What do you consider your primary field of research? (multiple choice)

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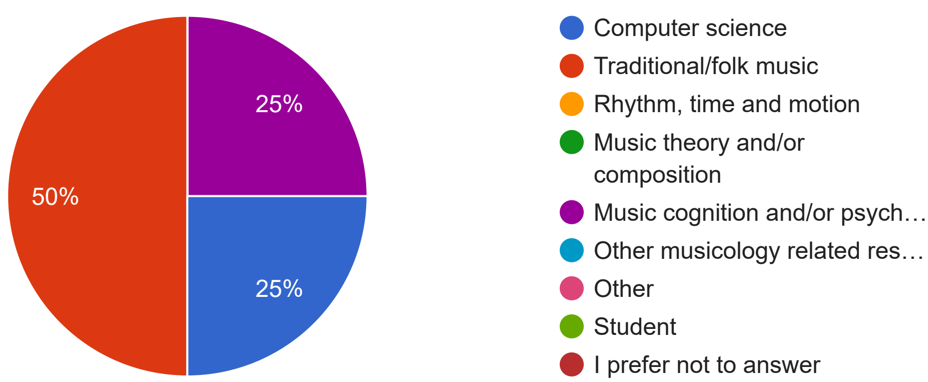

2. How familiar are you with the research and study of traditional Norwegian folk music?

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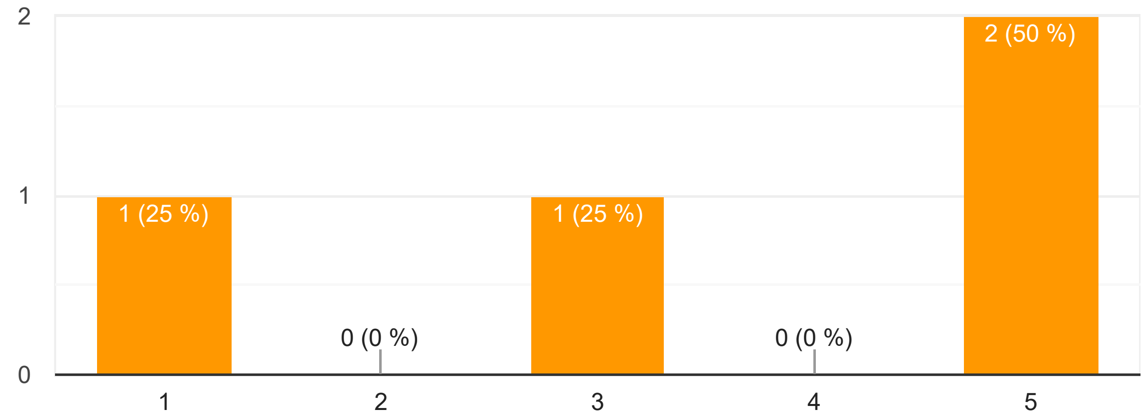

3. Do you perform or play Hardanger fiddle?

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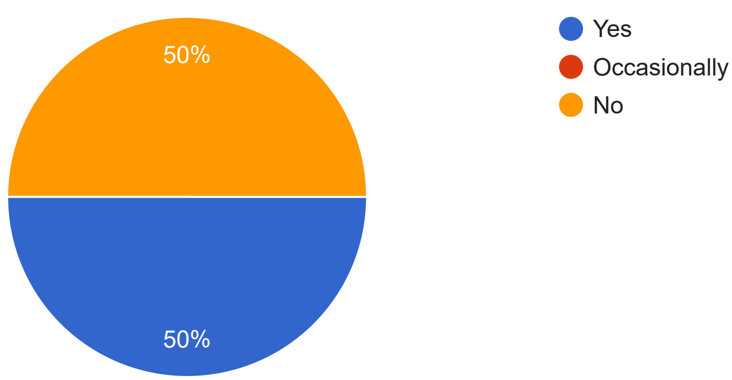

Interactive Tools in Research

4. In your professional career, have you ever felt the need for more personalized software tools for data management, pattern recognition or other research purposes?

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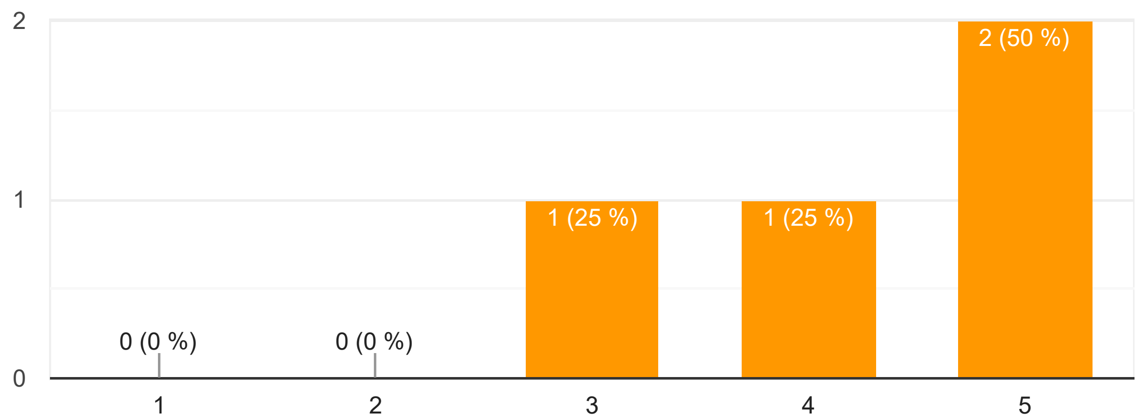

5. To what degree do you think interactive computational tools can contribute to Hardanger fiddle performance studies?

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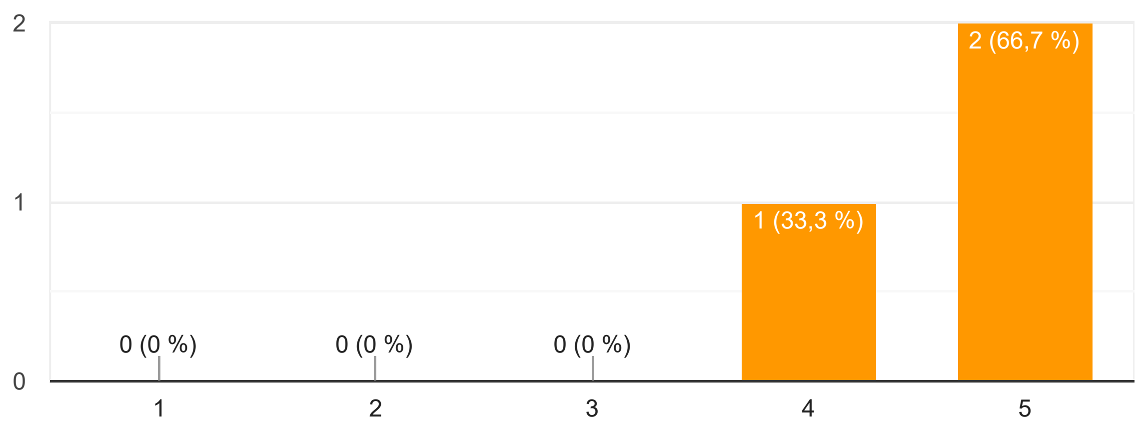

6. Would you consider using any of the presented tools for your own research and/or explorative purposes?

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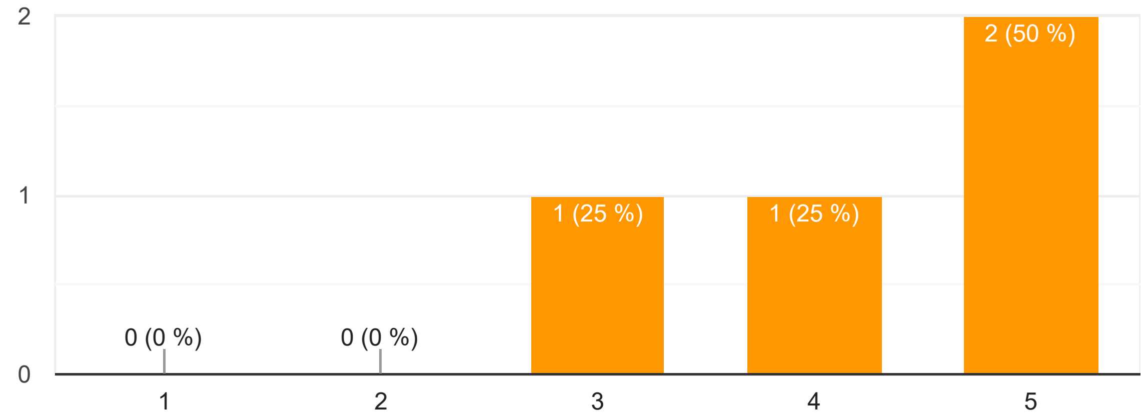

Toolkit Design

Tool nr.1 - Interactivity and engagement

7. The first tool has the ability to dynamically adjust beat position through an interactive interface. Do you think this feature could give players and researchers a better understanding of the asymmetrical timing patterns in Hardanger fiddle performances?

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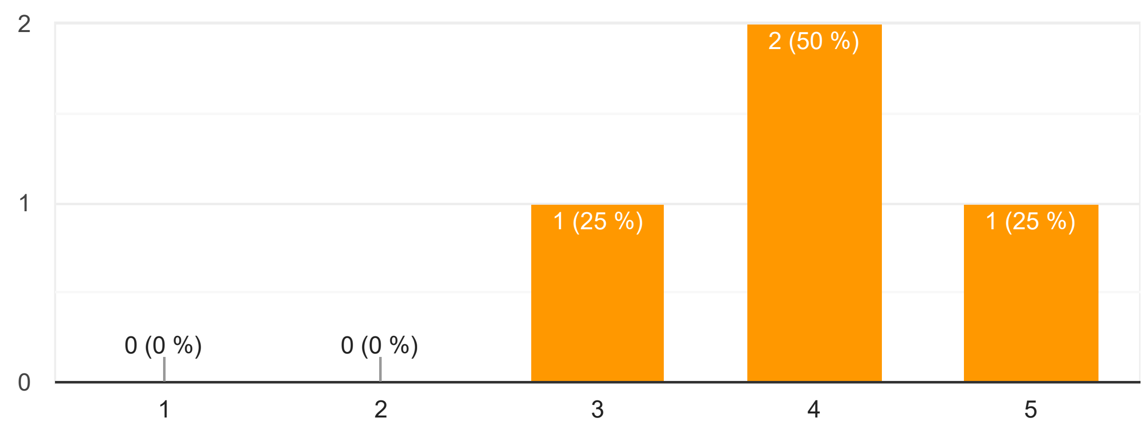

Tool nr.1 - A structural perspective

8. The first tool also has the ability to explore timing patterns of repeating sections and phrases. Do you think this feature could contribute to our understanding of performance patterns in Hardanger fiddle music?

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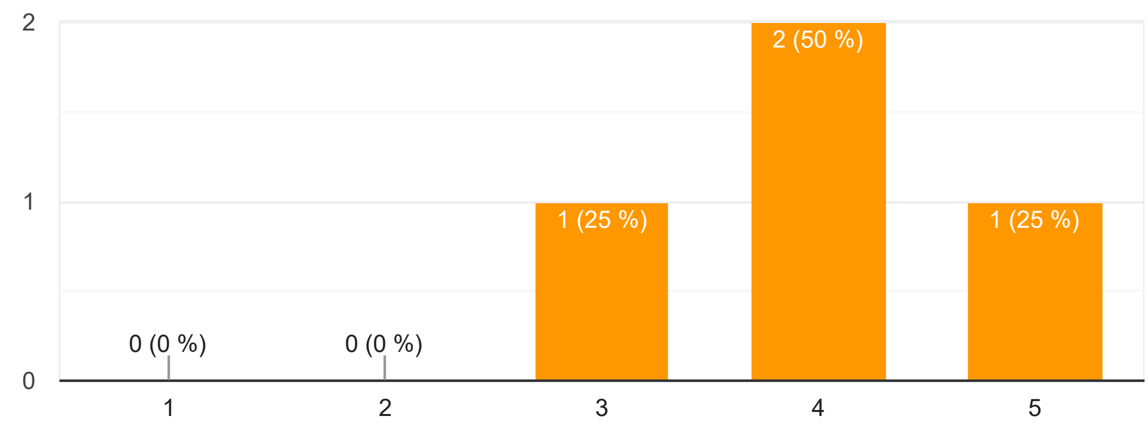

Tool nr.2 - Multi-dimensional analysis

9. The second tool has the ability to compare various properties of repeating timing patterns, for instance if regions with similar timing patterns share similar intensity, motivic/beat position and/or pitch content. Do you think this feature could contribute to our understanding of performance patterns in Hardanger fiddle music?

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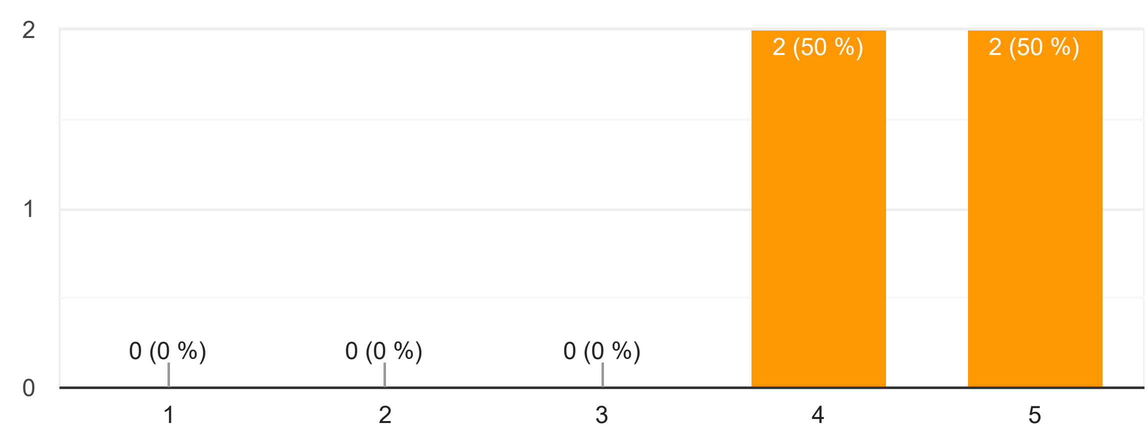

User Experience

10. The tools utilize various data visualization techniques, such as a unique score representation, coloring and dynamic plotting capabilities. Would you say these techniques increased the accessibility of the computational performance data?

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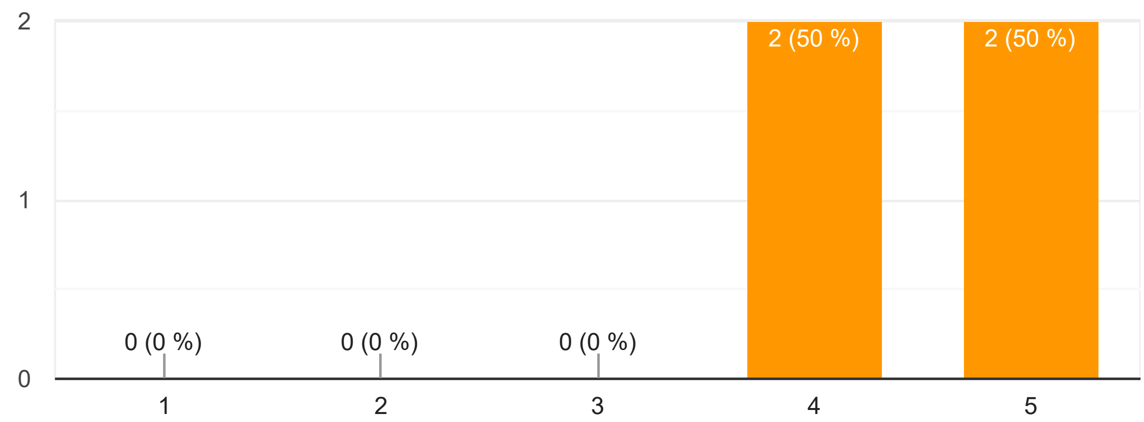

11. Do you think that research on musical performance patterns can benefit from improved data visualization techniques?

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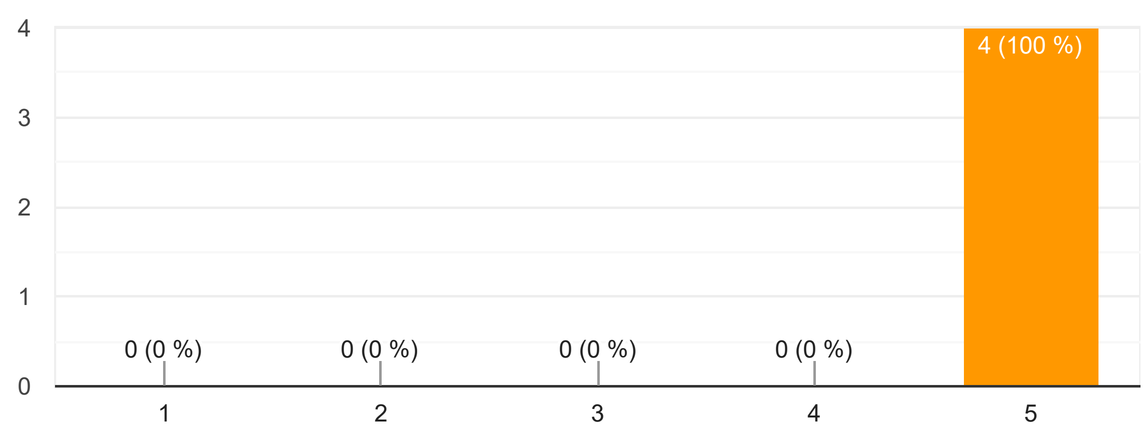

Alternative Approaches and Other Feedback

12. Imagine you were to acquire some personalized interactive software tools designed to contribute to your study or exploration of musical performance patterns. Please list a few features that you would like the tools to have.

4 svar

ease of import/export data in standard format (easy to integrate with other tools)

Don´t really know. I think to be able to record something and get sheet music as exactly as possible is a huge step forward.

multiple input sources: tapping, accelerometer (sp?), video

tempo, meter, pitch

13. Would you prefer your imagined set of personalized tools to be "modular" (a set of smaller tools) or singular (one "all-encompassing" tool)?

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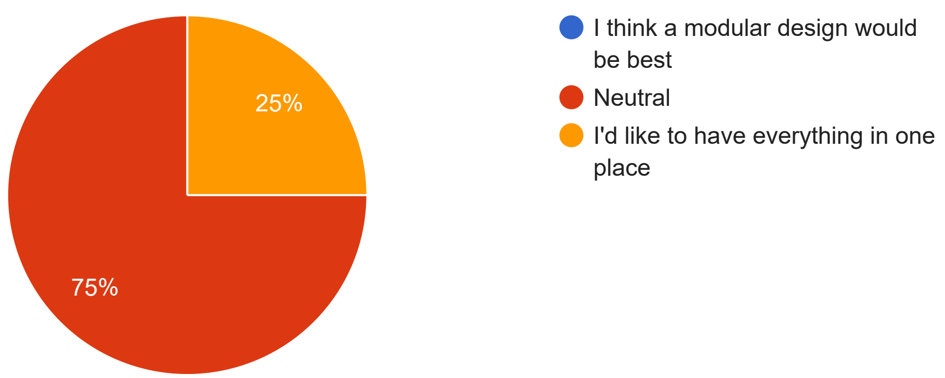

14. If you have more thoughts and/or feedback on matters relating to specific questions in the questionnaire, or just in general, please elaborate a sentence or two here. (Optional)

3 svar

the prototype in max is great, and within the scope of the thesis this is probably the only feasible path. But to benefit the community at large, this should be a standalone application non depending on max (perhaps something that runs in the browser!)

Interesting work!

My main interest is here what could be used on individual recordings and what could be used on large corpora and analyzed staticstically.

Appendix B

Python Notebooks

B.1 Operational Test 1

In [ ]:
```
import json
import pandas as pd
```

In [ ]:
```
def sd(array):
    mean = sum(array) / len(array)
    variance = sum([((x - mean) ** 2) for x in array]) / len(array)
    res = variance ** 0.5
    return res

def computeSD(df):

    sd_patternBeats = []
    for i in range(len(df)):

        # for every row in the dataframe.
        df_beatRow = df.loc[[i]]
        beatRow = df_beatRow.values.tolist()[0]

        # treat the row as a sample and calculate the SD.
        sd_patternBeats.append(sd(beatRow))


    mean = sum(sd_patternBeats) / len(sd_patternBeats)
    return {
        "SD of samples": sd_patternBeats,
        "Mean of SD": mean
    }
```

Compute beat duration variation in the "control structure"

Here we take every 1st, 2nd and 3rd beat in the performance, and calculate the SD respectively.

In [ ]:
```
data = "PATH-TO-FILE"
with open(data, 'r') as f:
    pattern_data = json.load(f)
    filename = list(pattern_data)[0]
    data = pattern_data[filename]
```

In [ ]:
```
beatRatios = data["ratios"]["beat_ratios"]
df_beatRatios = pd.DataFrame(beatRatios)
df_beatRatios.head()
```

In [ ]:
```
computeSD(df_beatRatios)
```

Compute beat duration variation of individual motifs

Here we calculate the standard deviation over the duration of every beat index in every motif.

In [ ]:
```
data = "PATH-TO-FILE"
with open(data, 'r') as f:
    patternData = json.load(f)
    filename = list(patternData)[0]
    data = patternData[filename]
```

In [ ]:
```
df_patternData = pd.DataFrame(data)
df_patternData.head()
```

In [ ]:
```
computeSD(df_patternData)
```