

## GROOVE: Mapping, Modeling, and Perceiving the Combinatorics of Groove-Based Rhythms

### 1 Excellence

#### 1.1 State of the art, knowledge needs and project objectives

While rhythm is a fundamental parameter of music that involves the durational patterns of musical sounds (London 2012), “groove” can be understood most simply as a musical genre’s ‘rhythm matrix’ (Monson 1996)—a typical combination of persistently repeated rhythmic patterns. **Groove-based musics dominate today’s soundscape and social dance culture**; they are among the most globally distributed forms of participatory music-making and listening. **Understanding how grooves are constructed—and how they elicit their characteristic aesthetic and bodily responses—can provide essential knowledge regarding how people organize and predict patterns in time, how we experience pleasure and reward, and build social connections across cultures.** The *GROOVE* project thus aims to provide new insights into groove by: (1) **mapping** how rhythms are uniquely combined in musical traditions that have had a significant impact on popular music, (2) **modeling** how such combinations of rhythmic patterns can be systematically described and categorized, and (3) **perceptually** testing how these combinations elicit a range of positive affective and aesthetic experiences across cultures. The project will employ recent theories from the fields of music theory and perspectives from rhythm cognition and timing perception, combined with computational approaches based on both conventional signal processing and AI techniques. This interdisciplinary synthesis of formal theory, automated analysis, and perceptual validation promises theoretical **advances in cognitive science and musicology, alongside practical insights for scholars and practitioners.**

While humans can theoretically produce countless rhythms, **real-world grooves appear to draw from a finite set of pattern archetypes** (Biamonte 2020; Câmara 2016; Danielsen 2006; Ohriner 2019; Traut 2005). Some such rhythms show more “symmetrical” *accent pattern* groupings—such as the ubiquitous *backbeat* rhythm (*accents*: one–and–two–and–three–and–four–and [242]), prominently featured in the most streamed Spotify song of all time (The Weeknd’s *Blinding Lights*)—while others are more “asymmetrical”, such as the *tresillo* rhythm (*one–and–two–and–three–and–four–and* [332]), common to a wide range of Afro-Caribbean and Afro-Latin genres and foregrounded in the second most streamed song (Ed Sheeran’s *Shape of You*; ChartMasters, n.d.). Crucially, **no single rhythm can fully account for groove**—the insistent *backbeat* of the drums in *Blinding Lights* shines brightest when heard against the ethereal syncopated melodies of the vocalist; the delightfully jagged *tresillo* of the marimba in *Shape of You* compels us to move to the beat more strongly when complemented by a subtle yet driving drum *backbeat*. Music theorists have posited that the very appeal of groove-based music lies within an aesthetic of “counter-rhythm”, where the contrast and integration of asymmetrically (“non-duple”) with symmetrically (“duple”) grouped rhythms plays a key role in eliciting a wide range of positive affective experiences, bodily engagement and social participation, as well as a sense of ‘flow’ (Câmara & Danielsen 2019; Cohn 2016; Ohriner 2019; Pressing 2002). Groove should thus be seen as **a multi-part combinatorial phenomenon whose aesthetic and affective power lies in the organization of pattern combinations across ensemble parts** (e.g., drums, bass, guitar, vocals). Groove *combinatorics* denotes the culturally constrained ways patterns are combined across instruments to form ‘groove archetypes’. So far, we lack any systematic knowledge about the combinatorics of groove and their effects. ***GROOVE* aims to fill this research gap by systematically identifying, analyzing, and categorizing patterns of rhythm and their combinations** with a focus on key **Afro-diasporic musical traditions** that have had an extensive impact on today’s popular music, **and explain the positive affect elicited by such combinations.**

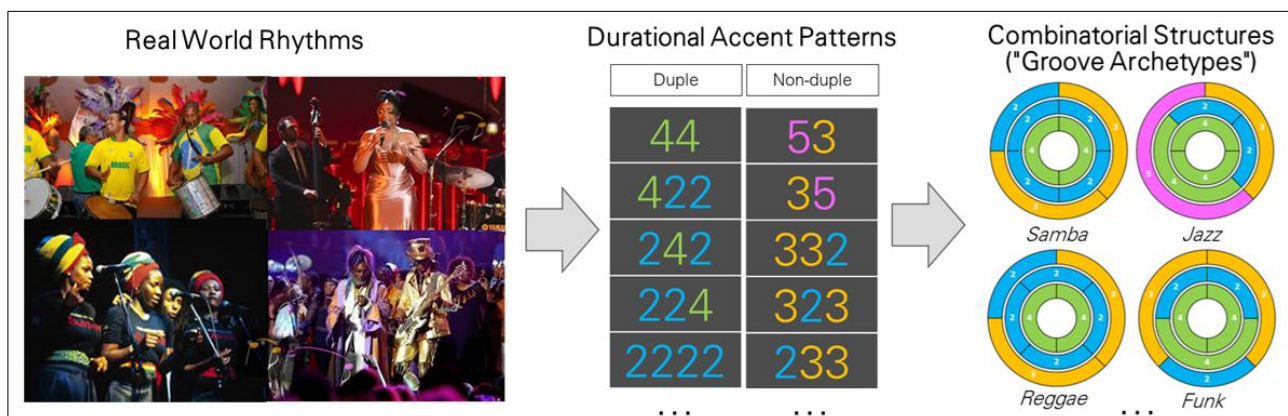


**Fig. 1** – Schematic illustration of how individual rhythms from different musical genres (left) can be categorized based on either symmetrical (duple) vs. asymmetrical (non-duple) durational accent patterns (middle), then mapped as unique combinatorial structures within and across genres (right).

In recent decades, interest in “groove” has emerged within cognitive science, where it has primarily been viewed as a universal experiential phenomenon related to the “pleasurable urge to move to music” (Janata et al. 2012; Madison et al. 2011). Such an embodied impulse has been linked to well-being, where engagement with groove-based rhythms has been shown to uplift mood and enhance cognitive performance (Orpella et al. 2025), as well as foster a sense of social connectedness across diverse global contexts (Duman et al. 2024; Swarbrick 2023). Groove has further been theorized to trigger such enjoyment through neural predictive processes, where rhythms predicted to elicit optimal groove experiences are those with moderate degrees of complexity that arouse sufficient interest while not being too difficult to synchronize along to the beat (Vuust & Witek 2014). Crucially, however, it has been shown that simply introducing complexity in a random and artificial fashion does not produce the same effect compared to naturalistic patterns derived from real groove-based traditions (Sioros et al. 2022). In other words, it appears that **pattern—not complexity in and of itself—matters**, and therefore **how patterns are combined** likely matters just as much, if not more, and may help explain why single-part complexity accounts of groove remain inconclusive (Senn et al. 2024). As such, *GROOVE* will aim to identify more precisely **what specific patterns of groove, and their resultant combinations, tend to elicit the pleasurable urge to move, and other positive affective experiences associated with groove-based music**. Furthermore, listener-related factors, such as genre preference and familiarity, have been shown to play an important role in ratings of groove-related aesthetic experiences (Jakubowski et al. 2022; Senn et al. 2018). Therefore, *GROOVE* will target participants from different cultures to further test how contingent such factors are on aesthetic preference ratings.

One main challenge in systematically identifying the structure of real-world rhythms is that it **requires a comprehensive formal theory of rhythm categorization and accompanying analytical frameworks**. While models for analyzing pitch-based melodic and harmonic relationships are a mainstay of music-education programs worldwide (e.g., Lerdahl & Jackendoff’s *Generative Theory of Tonal Music*, 1983), few comprehensive approaches to musical rhythm exist, and those that have been attempted tend to focus almost exclusively on Western art music genres that operate on entirely different rhythm aesthetics (e.g., Yust 2018). Formal methods for categorizing musical rhythm based on algorithmic approaches have been developed (Toussaint 2013) and recently applied to single-layered, monophonic, vocal rap rhythms (Condit-Schultz 2017; Ohriner 2019). However, **existing approaches have yet to be adapted towards multi-layered, polyphonic contexts**, such as the accompaniment section rhythms that form the very foundation of groove-based music. As such, *GROOVE* aims to **lay the groundwork for a general formal analytical-theoretical framework for groove combinatorics**. To gain a broader overview of trends both within and across genres, the project will also **develop computational tools for the automated categorization of groove archetypes**—patterns and pattern combinations—using a hybrid-AI approach combining traditional signal analysis techniques with machine learning. These will be applied to existing musical corpora (Bechtold et al. 2025) as well as novel corpora derived from commercial recordings—a task recently made feasible by advancements in source-separation algorithms that can parse out individual instrument layers from mixed-signal audio recordings (Zhang & Kim 2025).

**Beyond musicology, psychology, and informatics, the questions asked here are highly relevant to practitioners, composers, and teachers of groove-based music traditions, as well as the music industry.** The PI’s experience as a guitarist, percussionist, composer/arranger, and producer of groove-based genres (funk, reggae, samba/bossa-nova; 22 years) is that these are questions that are of particular interest not only to practitioners, but also educators of groove-based popular genres, who often rely on idiosyncratic approaches to groove performance and composition for the lack of more rigorous theories to draw from. In summary, by developing a novel theoretical-analytical framework for groove pattern combinatorics and computational tools for the application of such (*modeling*), then identifying groove archetypes across genres (*mapping*) and perceptually validating them via cross-cultural perceptual experiments (*perception*), *GROOVE* aims to provide insights into the role of rhythm in groove-based musical traditions and how it engenders positive affective experiences in a way that has significant academic impact, as well as being of practical use to performers, composers, and teachers.

## 1.2 Research questions and hypotheses, theoretical approach and methodology

**RQ1 (*mapping combinatorics*): How are pattern combinations uniquely configured and distributed across instruments in groove-based traditions that have significantly shaped popular music?** Utilizing a novel theoretical-analytical framework (outlined in RQ2) *GROOVE* aims to identify the relative frequency with which groove archetypes occur within and across genres. Here, a groove archetype refers to a recurring rhythmic combinatorial structure commonly found across different musical pieces within and across genres, which serves as a recognizable template or blueprint for how rhythm is produced and perceived. Rhythms in

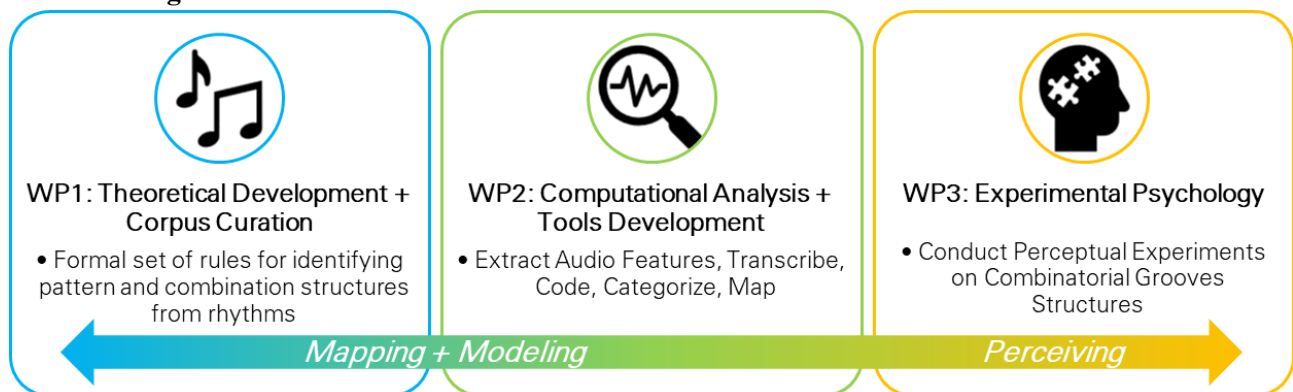
groove-based music have long been characterized as those replete with “syncopations”, a concept rooted in Western art music composition practices used to denote events that ‘violate’ expected metrical accentuation schemes, or the cognitive organizational structure with which we organize musical sounds in time (London 2012). One key novel approach *GROOVE* will take is recognizing that various Afro-diasporic groove-based traditions tend to value an overall rhythm aesthetic that promotes “perceptual rivalry” (Pressing 2002), or an energizing cognitive tension that arises when listeners simultaneously entertain competing perceptual interpretations of heterogeneous rhythmic layers against a steady pulse (Câmara & Danielsen 2019; Wilson 1974). As such, the appeal of grooves in such traditions does not at all lie in the asymmetrical or syncopated pattern of one rhythm layer alone (such as 3+3+2), but rather their very *combination* with symmetrical or unsyncopated ones (such as 4+4), whether it be in funk, samba, reggae, or salsa. Therefore, attention will be paid in mapping the unique ways in which rhythms are combined and distributed across different salient instrumental layers (e.g., drums, bass, guitar, keyboards) to form specific *groove combinatorics* with varying degrees of “counter-rhythm”, that is, how contrasting they are in terms of asymmetry/symmetry. It is hypothesized that certain archetypical pattern combinations will be prevalent across diverse genres and instrumental layers, while others will show strong genre-specific or culture-specific preferences. Overall, **by investigating grooves as holistic, culturally meaningful, and multi-layered combinatorial pattern structures rather than isolated rhythms that deviate from Western metrical expectation schemes, *GROOVE* aims to provide a crucial empirical understanding of the music that dominates our modern soundscape, based on novel theoretical insights.**

**RQ2 (*modeling combinatorics*): How can we theorize and analyze the categorization of rhythmic patterns and structures in groove-based music?** Various formal methods have been developed to quantify degrees of syncopation in monophonic (single-layered) rhythms (Longuet-Higgins & Lee 1984; Witek et al. 2014). While somewhat informative of the relative complexity of rhythms, these metrics by themselves do not provide much by way of specificity—for example, where precisely in a metrical scheme rhythms should be syncopated to denote any given genre or elicit a stronger affective-movement response, or how each instrument in a multi-layered groove-based ensemble should do so. More culturally appropriate conceptions of rhythm that take heed to African-derived practices of “cross-/counter-rhythm” (Câmara & Danielsen 2019; Danielsen 2006; Kolinski 1973; Locke 1982; Wilson 1974) suggest that groove-based rhythms instead be considered as *reiterated, patterned durations between perceived accents* (Ohriner 2019). An ‘accent’ here may be understood more simply as a perceptually salient event, which can be elicited by a change in a rhythmic event’s timing, duration, or loudness, amongst other acoustic factors (Câmara et al. 2020; 2023; Drake & Palmer 1993). A main challenge, however, is that real-world rhythms in African-derived genres do not always explicitly reveal immediate accent structures on the surface when analyzing audio signals from recordings (London et al. 2017). Furthermore, individual instrument rhythms tend to be far “busier” than potential accent patterns that may belie them, and musicians tend to vary such rhythms slightly during a performance in semi-improvisational fashion (Danielsen 2006). So far, methods to interpret underlying accent patterns in rhythms focus primarily on features such as onset timing (when a note occurs) and durations of notes (Toussaint 2013), with few exceptions where language and rhyme accent features have been considered for vocal rap rhythms (Ohriner 2019). However, no approach has yet fully accounted for pitch-related accents (tonal, harmonic, and melodic), which perceptual studies have shown to influence perception of rhythmic accent in music (Palmer 1996) and thus would be critical for identifying accent patterns in central accompaniment rhythms of chordophones (e.g., guitar, bass, piano) and aerophones (e.g., voice, trumpet, saxophone). On top of this, rhythm research—including groove research—focuses primarily on isolated monophonic ensemble parts, ignoring the fundamentally multi-part nature of music ensembles in groove-based genres. Critically, therefore, ***GROOVE* proposes the development of a novel, comprehensive model for categorizing cyclical groove pattern archetypes and combinatorics based on parameters of both rhythm as well as pitch and dynamics** to better account for the various salient accompaniment instruments that form the very foundation of groove-based genres.

**RQ3 (*perceiving combinatorics*): How do pattern combinations affect aesthetic and perceptual experiences of grooves?** This research question aims to more precisely identify which categorical pattern combinations (identified via RQ1 and RQ2) tend to elicit groove experiences such as the pleasurable urge to move, with focus on their combinations in multi-instrumental, as opposed to single-instrumental contexts, and in different genres and cultural traditions. Predictive coding theory of groove posits that preference for groove rhythms resembles an inverted U-shaped pattern: we derive greatest pleasure from moderately predictable patterns (medium syncopation) since those that are too predictable (low syncopation) lack surprise and interest, and those that are too unpredictable (high syncopation) become cognitively challenging and thus less

rewarding (Vuust & Witek 2014). While findings from multiple behavioral studies lend evidence to this theory (Etani et al. 2024), a robust restudy jointly conducted by key researchers in the field has recently yielded a null result (Senn et al. 2024), emphasizing concerns about the ecological validity of the stimuli used in the field (see also Senn et al. 2018; Spiech et al. 2023), including their exclusive focus on isolated rhythm patterns (monophonic drum rhythms), in contrast to the rhythm pattern *combinations* that characterize groove-based music and are focused in the current project. It would thus appear that the search for universal trends based on isolated rhythm patterns that often underlie cognitive groove studies inadvertently leads to the glossing over of the foundational characteristics of groove-based musical practices, which is its *multi-part* nature including the intricate differentiation and coordination of both simpler and more complex rhythm patterns and ensemble roles. Furthermore, recent studies have shown that both subjective experiences of difficulty (Hannon et al. 2012) and aesthetic preferences of the pleasurable urge to move (Jakubowski et al. 2022; Senn et al. 2018) are influenced in great part by listener-related factors such as genre preference and cultural familiarity, suggesting the patterns we find “groovy” are shaped by our biographical experience with certain patterns. In sum, **GROOVE will adopt a culturally and musically informed and thus realistic approach to understanding affective groove-related experiences and rhythmic pattern preferences, integrating both musical-structural and listener-related factors to deepen theoretical and empirical insights into groove aesthetics.**

### Work Packages



**WP1: Theoretical Development and Corpus Curation.** This work package addresses RQ1 and RQ2 and will focus on mapping and modeling groove combinatorics, devising a theoretical-analytical framework, centered on the formalization of a rule-based model for identifying accent patterns *and their combinations* across individual instrument layers. The PI will primarily be responsible for developing the theoretical foundation of the framework, building upon previous formal approaches of durational accents in rhythmic sequences (“groove class” analysis, Ohriner 2019) and extending it to factor in, first, further parameters of pitch, dynamics, and timbre, and second the combinatorics of pattern coordination in multi-part ensemble contexts. This approach will be informed by cognitive theories of musical meter and tonality (Lerdahl & Jackendoff 1983; London 2012) as well as musicological theories of counter-rhythm in groove-based practice (Câmara & Danielsen 2019; Danielsen 2006; Kolinski 1973; Locke 1982). The PI will also assemble a diverse corpus of groove-based recordings from influential Afro-diasporic genres, spanning African-American (e.g., funk, soul, hip-hop), Afro-Latin (e.g., samba, bossa nova, son, mambo), and Afro-Caribbean (e.g., reggae, ska, dancehall, calypso) repertoires to be made freely available online (deliverable D1), while leveraging and extending resources such as previously published data sets (e.g., Lucerne Groove Research Library, Bechtold et al. 2025). The PI will then work in tandem with the Post-Doctoral research fellow in WP2 to develop the necessary computational architecture to implement such formal rules to the corpus. The outcome is a combinatorial taxonomy linking instrument roles to recurrent cross-part pattern configurations.

**WP2: Computational Analysis and Tools Development.** This work package addresses RQ1 and RQ2, focusing on developing computational tools essential for implementing the theoretical-analytical framework established in WP1 on the selected musical corpus. The Post-doc researcher will lead the development of computational methods to systematically categorize groove patterns and their combinations. A hybrid approach combining traditional signal processing-based music information retrieval (MIR) and rule-based modeling with machine learning-based AI techniques will be employed. Specifically, this methodology will: (A) separate representative commercial recordings from each genre into distinct instrumental layers using audio source-separation algorithms (e.g., Demucs, Deezer/Spleeter) and extract audio features related to rhythm (onset timing, meter, tempo), pitch (tonal key, harmonic chord progressions), dynamics (intensity,

loudness), and timbre (brightness); (B) transcribe extracted rhythmic information into symbolic representations; (C) categorize these rhythmic representations according to archetype classes defined by the rule-based model in WP1; (D) map grooves by instrument and genre, using analytical approaches that measure structural similarities (e.g., clustering, phylogenetic analysis) to identify trends within and across musical genres. Special attention will be given to determining whether signal-processing tools, rule-based modeling, machine-learning algorithms (e.g., rule-extraction, autoencoders, clustering), or a strategic hybrid AI (Lartillot 2025) combination of these approaches most effectively perform each step. "Explainable AI" techniques will be explored, aimed at clarifying algorithmic decision-making processes, facilitating deeper understanding of rhythmic structures, including previously unidentified rhythmic patterns, and their combinatorics. The final outcomes will include computational functions for use in established audio and music analysis software packages (e.g., MIR Toolbox, Librosa) as well as an integrated, user-friendly data pipeline, all made freely available via an open-source repository (deliverable D3).

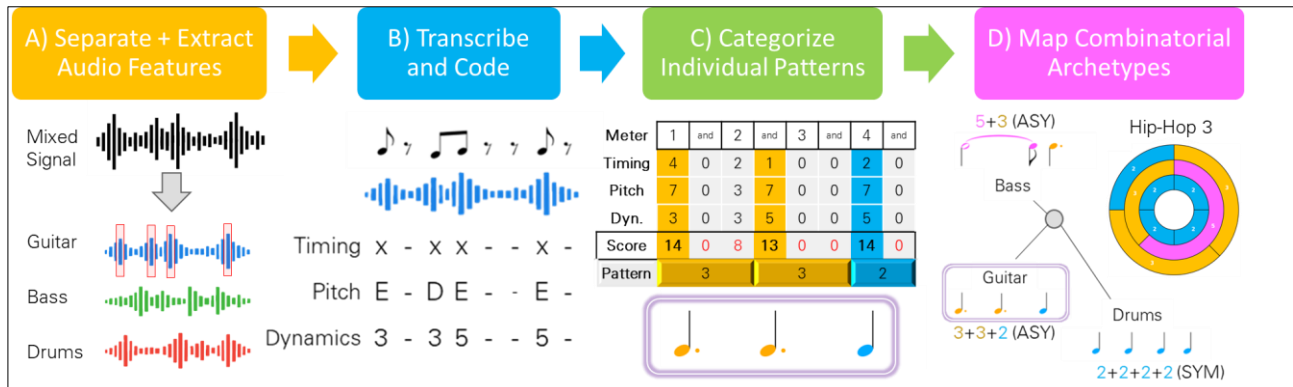


Fig. 2 – Overview of WP2 (Computational Analysis and Tool Development), where: A) corpus audio recordings are source-separated into individual instrument layers and audio features extracted; B) transcribed and coded into symbolic form; C) categorized under potential accent pattern archetypes according to formal rule set (WP1) based on a weighting/scoring system of each note's salient musical features; (D) mapped into combinatorial groove archetypes within and across instruments and genres.

**WP3: Experimental Psychology.** In this final work package, to address how a novel groove combinatorics model (RQ1 and RQ2) can be perceptually validated (RQ3), the PI will conduct behavioral listening (e.g., preference rating) experiments using both real-world and synthetically recombined multi-instrument examples of groove archetypes identified through WP1 and WP2. These will be tested in various multi-instrumental combinations, with special attention to how their internal relationships (e.g., between symmetrical and asymmetrical patterns) shape perceptual and aesthetic responses. Measures will include the degree of pleasure and urge to move, and listener-related factors such as familiarity and genre preference, and cultural background. Cultural background is also expected to play a role here, and as such, online platforms like Prolific will be used to recruit participants from diverse backgrounds, enabling cross-cultural comparisons of how groove archetypes are perceived. A standardized groove-rating questionnaire developed by Senn et al. (2020) in collaboration with the PI will be employed to ensure comparability with prior empirical findings. Rather than overall degree of syncopation—commonly understood as a proxy for ‘surprise’ regarding rhythmic sensory input given the brain’s model of metric expectation—the central hypothesis is that the appeal of groove-based music is driven by the degree of contrast between asymmetrical and symmetrical rhythmic layers, inducing a dynamic balance between metrical predictability and surprise: *H1 (Combination > Part)* predicts that multi-part combinatorial structure will explain ratings better than single-part syncopation metrics; *H2 (Contrast Sweet Spot)* predicts an inverted-U over inter-part contrast (symmetrical × asymmetrical), not over single-part syncopation; *H3 (Role Assignment)* predicts that the same pattern pair will yield different responses depending on which instrument carries the asymmetrical vs. symmetrical layer; and *H4 (Cultural Moderation)* predicts that genre familiarity and cultural background will modulate these effects. Together, WP3 provides the perceptual validation linking the combinatorial structural mappings from WP1–WP2 to experienced groove, while keeping stimuli ecologically grounded yet analytically controlled.

**Risk Management:** One technical risk in WP2 is potential inaccuracy in audio-source separation or feature extraction from commercial recordings, thus impeding accurate rhythmic categorization. To mitigate this, multiple functions and tools will be benchmarked during initial phases to ensure robustness. WP3 involves risks tied to online experimentation, such as inconsistent participant engagement and varied listening conditions. This will be managed through rigorous screening, large participant samples, and control checks. Additionally, if the theoretical and computational frameworks (WP1 and WP2) are not fully finalized in time, experiments in WP3 will proceed using established rhythmic patterns and combinatorial groove archetypes

identified from existing literature (Câmara 2016; Ohriner 2019; Toussaint 2013), ensuring productivity and meaningful data collection. Lastly, there is a risk that groove archetypes identified through theoretical (WP1) and computational analyses (WP2) may not clearly correlate with distinct aesthetic or perceptual experiences measured in experiments (WP3). Even in this scenario, documenting null results will be highly valuable, contributing significantly to debates around universal versus culturally specific rhythmic preferences. The interdisciplinary expertise of the PI, collaborative support from the Post-doc researcher, and institutional resources will significantly reduce the likelihood and impact of these risks.

**Interdisciplinary approach:** *GROOVE* adopts a deeply interdisciplinary framework, integrating concepts and techniques from music theory, analytical musicology, performance science, music information retrieval, signal processing, machine learning, and rhythm perception to address its core research questions. While this breadth introduces challenges—such as ensuring sufficient expertise across all domains—the PI has a proven track record of navigating these disciplines through active engagement and partnerships with leading scholars. To bolster this approach, *GROOVE* will engage specialists from the Local Expert Group at the Centre of Excellence for Interdisciplinary Studies in Rhythm, Time, and Motion (RITMO)/University of Oslo (UiO) and the Scientific Advisory Board, as well as recruit a Post-doc researcher to focus on the project’s computational and MIR components. Moreover, the host institution RITMO brings world-class, interdisciplinary strengths in rhythm and movement research—particularly in groove-based genres and computational methodologies—that perfectly complement the goals of *GROOVE*.

**Gender and diversity perspectives:** *GROOVE* will engage primarily with groove-based musical genres historically rooted in Afro-diasporic cultural practices, thereby highlighting contributions by, and promoting representation of BIPOC in its analytical focus. The project also recognizes the gender imbalance typically observed within these musical traditions, where instrumental roles—particularly rhythmic instruments—have predominantly been occupied by male musicians, while women have historically been positioned as vocalists. To address and mitigate this imbalance, the project will actively seek to incorporate and highlight recorded examples prominently featuring women instrumentalists, whose contributions to groove-based music are often marginalized or overlooked in academic and popular representations. The PI is also aware of the pronounced gender disparities present within computational musicology, and in line with RITMO’s Diversity Action Plan, will actively pursue gender balance in recruitment processes, prioritizing diversity in the composition of the research team. Additionally, efforts will be made to recruit a diverse and representative participant pool for the behavioral experiments, ensuring varied representation across gender, ethnicity, and cultural backgrounds.

### 1.3 Ethical issues

*GROOVE* will involve use of audio source separation algorithms on commercial music recordings, an approach increasingly common and generally accepted as fair use for scholarly and educational purposes (Zhang & Kim 2025). Behavioral experiments will also be conducted both live and online, requiring careful adherence to ethical standards regarding participant consent and data protection. For live experiments, informed consent will be explicitly obtained, and collected data anonymized, strictly following UiO’s ethical guidelines. Online experiments will collect only basic demographic information, maintaining participant anonymity by default. All data collection and processing activities will comply fully with GDPR and be registered with the Norwegian Agency for Shared Services in Education and Research (SIKT). Participants will be clearly informed about the project’s goals, methods, procedures, data handling practices, and intended research outputs prior to data collection.

### 1.4 Novelty and ambition

*GROOVE* is distinctly innovative in four key respects. Firstly, it will be the **first to link specific groove pattern archetypes and their multi-instrumental combinations to aesthetic preference** (pleasure, urge to move) **and listener-related factors** (familiarity, genre preference) via perceptual experimental methodologies. It will also contribute to new knowledge regarding cross-cultural effects of groove patterns on aesthetic experiences via large-scale online experiments, generating novel insights into **universal versus culturally contingent rhythmic preferences**—a topic on which research remains scarce (Bechtold et al. 2024). Secondly, it aims to develop the **first comprehensive theoretical–analytical framework** for systematically identifying and mapping **the structure of real-world rhythms in multi-layered, polyphonic contexts**. By integrating **both rhythm and pitch-related parameters** to previous monophonic “groove class” methods (Ohriner 2019), it will offer the field a formalized, more generalizable theory of groove pattern structures. Thirdly, it will generate new theoretical insights into rhythm perception by **testing how perceptual rivalry between contrasting symmetrical and asymmetrical rhythmic patterns may underlie the pleasurable urge to move** and other positive affective experiences of groove. These findings will **inform broader rhythm**

**cognition debates—especially the predictive coding theory of groove**—by assessing whether deviations from the expected “inverted-U” preference curve are better explained by structural or cultural parameters. Last, but not least, the project aims to deliver the field’s first **fully integrated computational pipeline for groove analysis**. Starting from mixed-audio recordings, the package will perform automatic stem separation, extract multi-dimensional features (onset timing, duration, tonal accents, dynamics), classify patterns based on a formalized rule set, and finally **map and visualize groove combinatorial structures**. By uniting these components into an open-source toolbox, it aims to set a new benchmark for reproducibility and accessibility in music analysis and music information retrieval of popular music. This synthesis of formal theory, automated analysis, and perceptual validation promises both theoretical breakthroughs in cognitive science and musicology, and practical insights for scholars and practitioners alike.

## 2 Impact

### 2.1 Potential for academic impact of the research project

The *GROOVE* project will deliver significant academic impact across multiple disciplines, including rhythm perception and cognition, music psychology, music theory, and computational musicology. By developing the first comprehensive framework for identifying and categorizing groove pattern archetypes in real-world groove-based music, the project addresses a long-standing gap in the music sciences. These archetypes—understood as recurring multi-layered rhythmic combinations with cultural and cognitive salience—will be analyzed not only in terms of their metric structure but also their perceptual and affective effects and inter-instrumental relationships. **By rooting the analytical framework in Afro-diasporic rhythmic practices and theories of counter-rhythm**—rather than classical Western notions of syncopation—the project reframes how rhythm and time are understood across musical and cognitive sciences.

Empirically, *GROOVE* advances understanding of the aesthetic and perceptual mechanisms of groove through behavioral experiments (WP3) that test how listeners respond to different combinatorial groove archetypes and their configurations across instruments and genres. These experiments will probe listener responses to multi-layered rhythmic interactions between symmetrical and asymmetrical patterns, testing the hypothesis that perceptual rivalry between contrasting rhythms contributes to the many positive affective responses to groove, such as the pleasurable urge to move. The results will **directly inform current theoretical debates in rhythm cognition and neuroscience, like the predictive coding theory (Koelsch, Vuust & Friston 2019), by testing whether real-world groove archetypes conform to this theory’s predictions**. Is, for example, the hypothesized preference for moderately predictable rhythms correct (Vuust & Witek 2014), or can deviations from it be better explained by pattern combinatorics and role assignment, or cultural parameters not yet examined? This is of particular relevance since null results from a recent study using real drum rhythms from groove-based repertoires (Senn et al. 2024) cast doubt on previous findings and suggest that fundamental structural and perceptual aspects of groove are yet to be understood. Importantly, the project also addresses growing concerns around cultural bias in psychology by recruiting a globally distributed participant sample through online platforms, enabling more robust cross-cultural analysis of groove preferences and rhythmic processing. More broadly for psychology, the project will inform how the brain binds parallel rhythmic streams into a single predictive–motor plan, specifying when and why cross-part contrast tips perception from merely ‘interesting’ to highly ‘compelling to move’ to ‘incomprehensible’. **The cross-cultural design also helps separate universal from learned aspects of temporal coordination, informing core theories of predictive processing, attention, reward, and social entrainment well beyond music.**

Theoretically, *GROOVE* combines theories of African-American and African rhythms (Abel 2014; Câmara & Danielsen 2019; Locke 1982; Wilson 1974) with recent developments in formal rhythm analysis (Ohriner, 2019; Pressing 2002; Toussaint, 2013) by adapting and extending “groove class” methodologies for multipart, accompaniment-based musical contexts. The project also introduces pitch and dynamics-related accent structures into the analysis of rhythm, expanding the scope of what rhythmic complexity entails. These theoretical insights will be formalized into a new rule-based system (WP1), implemented through hybrid-AI computational methods (WP2), and validated through perceptual data (WP3). For informatics/MIR, the project will deliver a labeled corpus that can raise the ceiling on MIR tasks—improving source-separation quality control, onset detection, beat/downbeat/meter tracking, pattern discovery, and genre attribution by modeling inter-part relations rather than single streams. Its explainable, human-auditable pipeline for detecting and validating pattern combinations **will offer a template for interpretable multi-stream time-series analysis—transferable to speech and gesture, bio-physiological signals, and human-computer interaction**—pushing feature extraction and evaluation beyond black-box accuracy.

By integrating theoretical, computational, and empirical approaches across disciplines, *GROOVE* is positioned to make lasting contributions to the scholarly study of rhythm. All theoretical outputs (e.g., pattern

taxonomies, accent models), curated data (e.g., annotated corpora), and software deliverables (e.g., analytical packages) will be made available open access in accordance with FAIR data principles, maximizing reusability. These resources are designed to serve as reference tools for researchers working at the intersection of rhythm theory, music technology, and cognition.

## 2.2 Potential for societal impact of the research project

Beyond its academic value, *GROOVE* has concrete societal implications for music education, cultural understanding, and the broader creative sector. The project provides educators with an evidence-based system for teaching groove and rhythm that moves beyond intuitive or stylistically limited approaches. By identifying systematic rhythmic archetypes and their combinations across instruments and traditions, *GROOVE* contributes tools that can directly inform music pedagogy in formal and informal settings, particularly in jazz, funk, hip-hop, and other popular music curricula. Importantly, the core message of the project that groove derives from the combination of asymmetrical and symmetrical—that is, complex and simple patterns—has fundamental implications for teaching strategies, as the theoretical contribution of simple—but nonetheless equally relevant—patterns allows for the development of—and lowers the threshold for—inclusive, participatory approaches to overall complex musical practices and experiences. This aligns with **UN Sustainable Development Goal 4 (Quality Education)**, by **fostering inclusive and contextually grounded rhythm education across cultures and genres**.

The project also contributes to **SDG 10 (Reduced Inequalities)** by **highlighting rhythmic traditions rooted in the African diaspora—traditions that have historically been underrepresented in academic discourse despite their enormous cultural influence**. Through corpus selection, analytical framing, and dissemination strategies, the project explicitly centers African-American, Afro-Latin, and Afro-Caribbean musical traditions, offering not only analytical recognition but also tools that can assist in the preservation and appreciation of these rhythmic lineages in both academic and public spheres.

Further societal relevance lies in the potential applications of groove analysis in therapeutic and creative contexts. Insights into **rhythm-induced movement and pleasure** may be applied in music-based **therapy, rehabilitation, and well-being programs**. These insights could also inform new interfaces and generative tools in the creative industries—particularly those developing rhythm-aware music applications or training platforms. Finally, the open-source nature of all *GROOVE* tools and data ensures accessibility for a broad audience of practitioners, educators, and learners across socioeconomic and geographic boundaries.

## 2.3 Measures for communication and exploitation

*GROOVE* will employ an integrated strategy to ensure wide dissemination and exploitation of its results, both within and beyond academia. Scientific results will be presented at leading international conferences in musicology, music cognition, and computational music research, including ISMIR, ESCOM, ICMPC, and RPPW. Peer-reviewed articles will be submitted to interdisciplinary music-theory and psychology journals such as *Music Perception*, *Music Theory Spectrum*, and *Cognition* as well as computer-science journals such as *TISMIR* (deliverables D2 and D4). Outputs will follow UiO's rights retention policy and be published open access to ensure prompt and universal accessibility. The project's technical outputs—including the *GROOVE* Combinatorics analytical framework, feature extraction functions, annotated corpora, and all source code—will be shared through GitHub, Zenodo, and UiO's open repositories, with accompanying documentation to enable transparency and reusability. These will be maintained according to FAIR data principles and designed to serve both academic and applied communities, including educators and developers (deliverables D1, D3).

To reach practitioners and public audiences, *GROOVE* will organize a workshop in collaboration with music festivals (Oslo World Festival, ByLarm), educational institutions (Norwegian Academy of Music, UiO Dept. of Musicology) and industry organizations (TONO, Gramo) (deliverable D5). This will focus on demonstrating how groove pattern analysis can inform rhythm pedagogy, performance training, and creative practices. A dedicated online platform will also allow users—musicians, students, researchers—to interactively explore and experiment with groove pattern structures across genres and instruments. In parallel, the project will engage with public media outlets—including music-focused podcasts, science communication blogs, and national radio and newspapers—to communicate key findings in accessible formats and highlight the broader cultural relevance of rhythm research. Together, these communication and exploitation measures ensure that *GROOVE* will leave a lasting footprint in both academic infrastructure and the public understanding of musical rhythm.

### 3 Implementation

#### 3.1 Project manager and project group

The **Project Manager**, Guilherme Schmidt Câmara, is an interdisciplinary musicologist specializing in timing, rhythm, and groove-based music. His academic output integrates socio-historical, music analytical, empirical performance, cognitive psychological, and computational approaches to the investigation of groove-based music. Câmara played a central role in the RCN-funded TIME (Timing and Sound in Musical Microrhythm) project at the RITMO Centre led by Prof. Anne Danielsen. There, he led and coordinated a performance-experiment oriented work package involving audio and motion capture analyses, and qualitative interviews with over 60 professional groove-based musicians. Câmara has also contributed to behavioral and physiological studies related to the perception of timing and rhythm in groove and the development of a standardized questionnaire for the experience of groove as an experiential phenomenon. Despite his early-career researcher status, Câmara is already being recognized as a leading expert in the field of groove-based performance and perception, and his growing publication record in leading international journals and edited volumes frequently involves collaboration with scholars from psychology, informatics, and musicology. His ongoing research, funded by RITMO, advances knowledge on perceptual thresholds and subjective preferences related to timing in groove-based music contexts, developing practical heuristic tools for both scholarly analysis and music production. Câmara has also worked professionally as a groove-based musician; both as performer (guitarist), composer/arranger, as well as music director of television music programs. The **Project Owner** (RITMO/Department of Musicology) at UiO is committed to hosting the project and developing this area of research, and has hired the project manager (Câmara) as Post-Doctoral research fellow since 2022.

In addition to **directing the project**, the Project Manager will be **responsible for theoretical development** (WP1), **and psychological experimentation** (WP3), as well as contribute to/supervise development of the computational analysis and tools component (WP2). The **Project Group** will include one research fellow (Post-doc) in Oslo:

- Post-doc (100%, 3 years): will have a background in music information retrieval/music technology and computer science, including AI/machine learning, preferably with knowledge of audio source-separation and feature extraction. The fellow will be responsible for the computational extraction of audio features/analysis of the corpus (WP2) and contribute to the implementation of the theoretical-analytical framework (WP1).

In addition:

- Students in Oslo will support research activities in domains including data infrastructure, data collection and corpus curation, rhythm transcription, internet presence, and organization of events. Master's students may be recruited to work on topics related to the project.

A **Local Expert Group (LEG)** at UiO will closely accompany the project, advising the team members, collaborating directly on work packages, and co-authoring research papers:

- Prof. Anne Danielsen; African-American music, rhythm analysis, cognitive rhythm studies; (WP1), (WP3)
- Prof. Alexander Refsum Jensenius; music information retrieval, artificial intelligence (WP2)
- Prof. Bruno Laeng; psychology of aesthetics: experimental design and analysis (WP3)
- Dr. Olivier Lartillot; music information retrieval, computational analysis; (WP2), Post-doc co-supervisor
- Prof. Rainer Polak; ethnomusicology of West Africa, rhythm and timing perception; (WP1)
- Prof. Kyrre Glette; artificial intelligence, evolutionary computation; (WP2), Post-doc co-supervisor

The **Scientific Advisory Board (SAB)** will comprise the following:

- Justin London (Carleton College); music theory, rhythm and perception studies
- Maria Witek (University of Birmingham); music psychology of groove, cognitive rhythm studies
- Henrik Hellstenius (Norwegian Academy of Music); composition, music theory, performance
- Mitchell Ohriner (University of Denver); music theory and computational musicology of groove,
- Nicole Biamonte (McGill University); music theory of popular music, rock performance and composition
- George Sioros (University of Music and Performing Arts Vienna); music information retrieval, rhythm cognition of groove
- Olivier Senn (Lucerne University of Applied Sciences & Arts); music psychology, groove-rating studies

Several SAB members will also contribute directly to the project: Sioros will assist with computational analyses, including AI/machine learning methods (WP2) and theorization (WP1); Witek and Senn will contribute to experimental design and analyses (WP3); London, Ohriner, Biamonte, and Hellstenius will contribute to theorization (WP1).

### 3.2 Project organization and management

**Work Plan:** The Gantt chart in Table 1 illustrates the structure of the project.

| Year                          | 2026 | 2027 |    |    |    | 2028 |    |   |    | 2029 |   |    |    |
|-------------------------------|------|------|----|----|----|------|----|---|----|------|---|----|----|
| Quarter                       | 4    | 1    | 2  | 3  | 4  | 1    | 2  | 3 | 4  | 1    | 2 | 3  | 4  |
| Milestones                    | M1   |      | M2 | M3 | M4 |      | M5 |   | M6 | M7   |   | M8 | M9 |
| WP1 (Theoretical + Corpus)    |      |      |    |    |    | D1   |    |   | D2 |      |   |    |    |
| WP2 (Computational)           |      |      |    |    |    |      |    |   |    | D3   |   |    |    |
| WP3 (Experimental)            |      |      |    |    |    |      |    |   |    |      |   | D4 |    |
| Project Manager               |      |      |    |    |    |      |    |   |    |      |   |    |    |
| Post-Doctoral Research Fellow |      |      |    |    |    |      |    |   |    |      |   |    |    |

Table 1 - Gantt chart for GROOVE, with individual lines for work packages (WPs) and indications of milestones and deliverables. General project milestones are included at the top and the working periods of project members at the bottom.

#### Milestones

- **M1:** Team recruitment, ethics approvals, launch project website
- **M2:** First SAB meeting with project group after Post-doc fellow arrival
- **M3:** Corpus curation complete (WP1)
- **M4:** Theoretical framework and first computational analysis implementation complete (WP1, WP2)
- **M5:** Submission of music-theory and computer science articles; piloting psychological experiment (WP3)
- **M6:** Data collection for online perceptual experiments complete (WP3)
- **M7:** Submission of psychology journal articles; publication of software toolbox (WP2)
- **M8:** Final SAB meeting and *GROOVE* workshop
- **M9:** Project closure (final report and webpage, wrap-up of data archiving and publication)

#### Deliverables

- **D1:** Open-source publication of corpus (audio + annotated symbolic dataset)
- **D2:** Publication of approx. 2-4 peer-reviewed journal articles/conference proceedings in music theory and computer science related journals
- **D3:** Open-source publication of computational functions and data pipeline for automated audio feature extraction and pattern combination categorization
- **D4:** Publication of approx. 2 peer-reviewed journal articles in psychology related journals
- **D5:** Public workshop and interactive website demonstrating mapped groove patterns and analysis tools

**Research Infrastructure and Environment:** The project will be hosted at the Department of Musicology (IMV) and the RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion, at the University of Oslo, a world-leading environment for interdisciplinary rhythm research comprised of approximately 60 researchers across the arts and humanities, social sciences, and formal sciences. RITMO and IMV provide access to advanced facilities and software licenses for music information retrieval (WP2), perceptual experimentation (WP3), secure server space for data storage, and support from UiO's IT, legal, and administrative services. All data and code will follow UiO data management policy and GDPR. The Department of Musicology also hosts the MishMash Centre for AI & Creativity, a newly established center for AI and creative practice. The research at MishMash will inform *GROOVE* regarding the use of AI methods relevant to our computational pipeline and provide a forum for responsible-AI practices (ethics, IP, and openness) directly applicable to our corpus, tools, and dissemination. The project will be fully integrated into RITMO and Department of Musicology's research communities, with team members participating in seminars, workshops, and center-wide knowledge-exchange events. This environment—augmented by MishMash's creative-AI ecosystem—provides the personnel expertise, infrastructure, and collaborative channels necessary to deliver the project's theoretical, computational, and experimental objectives.

**Organization and Management Structure:** Project progress will be monitored through weekly meetings between the PI and Post-doc, who will jointly oversee progress toward deliverables and ensure alignment with timelines. The Local Expert Group will be consulted regularly, with one-on-one meetings timed to coincide with critical stages (e.g., testing of analytical rules, experiment design) as well as full-team meetings with all members once per academic semester. In-person SAB meetings are planned for the first and last year of the project, with additional virtual meetings the second year, and additional small-group and one-to-one virtual meetings in between as needed. RITMO's administration will provide logistical and operational support. The structure is designed to promote strong interdisciplinary collaboration, ensure accountability, and allow for adaptation as the project unfolds.

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