Music Score Analysis with Process Mining

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Abstract—Process mining is applied to a wide variety of use cases, most typically for processes like order-to-cash and purchase-to-pay. Respective algorithms are able to discover bottlenecks, identify recurring patterns and deal with concept drifts. So far, use cases in cultural heritage scenarios are scarce. Yet, music scores provide an ideal opportunity for process mining algorithms; they are structured into notes, measures, repetitions, parts, instruments, etc. Additionally, compelling characteristics are inherent, like varying dynamics, transformations by modulations, and phase delays such as in a fugue. In this demo article, we present a tool that is able to do process-style analysis of music scores. Most notably, it transforms scores into an event log and performs basic process discovery. We see potential not only for music theorists, but also as pedagogical tool to illustrate process mining concepts and as a means to produce event logs for advancing process mining techniques.

Index Terms—Process Mining, Music Analysis, Cultural Heritage

I. INTRODUCTION

Process mining is used in a wide variety of use cases for all kinds of industrial and societal processes [1]. Event logs are at the baseline, they contain sequences of events that describe the execution of a process. Taking event logs as starting point, process mining can be used to automatically discover, monitor, and improve processes. For example, it can discover how a process is actually being executed, to find bottlenecks, or to identify opportunities for improvement. Process mining is a relatively new field, yet it is a valuable tool for any organization that wants to improve its business processes.

Use cases in the field of cultural heritage are rare so far. For instance, process mining techniques have been compared to the methodological tool chaîne opératoire common in archaeology [2]. We have not found any applications of process mining in music, despite the obvious parallels: Music pieces are usually denoted in a strongly formalized notation called scores. Especially orchestral pieces deal with a lot of concurrency by the instruments; in history, there were quite a few genres with similar patterns like repetitions and variations. We postulate the following research question: How can music scores be processed so that existing process mining tools can be used to analyze musical pieces?

In this demo paper, we present a proof-of-concept tool that is able to transform musical scores in the popular MusicXML notation to event logs. This enables new interpretations of musical art, for instance, by analyzing rhythm and repetitions in a process-oriented visualization. Specifically, we encode a piano piece of a recent number one hit single as event log. The visualized results are surprisingly clear. Therefore, we are optimistic that this type of analysis can help advance not only music theory but also process mining by making the large body of music scores available as event logs. Our tool can also be used as a pedagogical instrument to vividly explain business process management concepts.

II. PARALLELS TO PROCESS ANALYTICS

Regarding music and data mining, there not many related work applying standard data mining methods to music; a notable exception is the book Music Data Mining [3]. Baratè et al. present a musicological analysis with Petri nets as formal tools for studying concurrent, asynchronous, and parallel processes [4]. They focus on extracting groups from music scores as objects, such as episodes, themes, and rhythmic patterns, to visualize them as transition system. Musical set theory as a subdiscipline of music theory similarly organizes musical objects and describes their relationships to discover deep structures (e.g., [5]).

Besides the concurrency and repetitional characteristics, there are further features in music scores with exemplary equivalents in process analytics (in alphabetical order):

**Chord** Group of multiples notes played together; stands for activity variants.

**Dynamics** The volume of (a sequence of) notes; could represent the amount of resources consumed.

**Modulation** Refers to a key change, if a melody is replayed on a different base note; corresponds to concept drifts.

**Note** Basic unit of a score, besides pauses; can be considered the most fine-grained activity.

**Repetition** Looped parts, often explicitly denoted variations; stands for re-executions.

**Rhythm** A sequence of beats forming recognizable patterns; could represent the timing of events.

**Tempo** How fast the piece is played, corresponds to the execution speed.

Typically, these are combined in infinite possible variations. Throughout history, particular styles have formed, such as the fugue, where a musical theme is repeated in various pitches and through different instruments. It is trivial to see further parallels to process mining techniques such as frequent pattern mining and local process models.

III. MINING APPROACH AND EXAMPLE

Our general approach is as follows. First, we parse a digital music score file. Currently, the entire piece of music is considered as one case. In a preprocessing step, we either
IV. DISCUSSION AND OUTLOOK

In this paper, we positioned process mining as technique to analyze music. This is possible, since music scores share many characteristics with business processes. As proof-of-concept, we presented a tool that transforms musical notation into event logs, so that hundreds of process mining techniques can be applied directly. In the demo, we analyzed the 2022 hit “As It Was” by Harry Styles, by transforming a piano arrangement as event log and creating a DFG.

As a next step, we plan to realize further activity notions beyond measures, such as complete melodies, and thereby validate event abstraction techniques. Similarly, we experiment with our case notion to possibly infer the process behavior of entire musical epochs. With Object-Centric Event Logs, we could model the concurrent interplay of multiple instruments and the resolution of measures to notes. We plan to discuss our tool with music theorists to evaluate its applicability. It could give a new perspective for the analysis of large music collections, e.g., the whole Köchel catalogue, a collection of compositions by Wolfgang Amadeus Mozart. Process models as preprocessed scores could also serve as intermediary inputs to machine learning algorithms that output creative compositions or be used to explain them. Given the large body of available music scores, our tool could help advancing process mining techniques by providing countless (acoustically replayable and explainable) examples for training, or be used in teaching to illustrate BPM concepts.

Besides music scores, our approach is easily transferable to streaming settings by capturing live music. This would make the parallels to techniques such as conformance checking even clearer, as slight variations like length and hitting a wrong note are recognizable as deviations.

REFERENCES