(Un)Like Schumann: Applying Cope's Music Signature Pattern Matching Algorithms to Tchaikovsky's Children's Album

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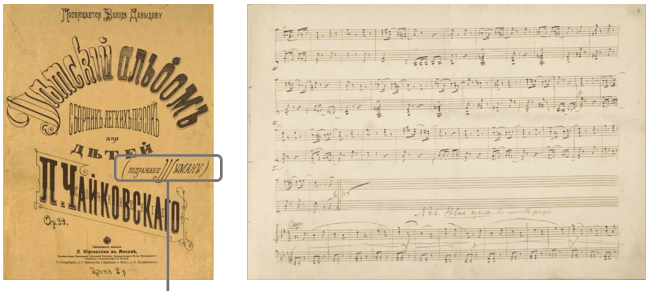
***Abstract*—This paper describes a preliminary study looking into applying pattern matching algorithms working with music signatures to the "Children's Album" by Pyotr Tchaikovsky. Though music signatures introduced by Cope are usually used for author identification and computer music generation, we make an effort to use them for analysis of origins and links of the existing compositions. We take Tchaikovsky's "Children's Album" as an interesting case, where we can try to apply the computational models to resolving the questions, which are usually mostly in scope of musicology studies. Specifically, our experiments demonstrate that one can find only a few Schumann signatures in the pieces from the "Children's Album", in contradiction to the Tchaikovsky's note in the published version claiming the imitation of Schumann's approach. Thus, our experimental results can provide additional important insights for musicologists searching to unravel the possible reasons of significant transformations that occurred on the way from the accurately organized manuscript to the first published edition. The previous studies addressing this issue are mostly in the scope of music theory, with almost no involvement of computational approaches to music analysis. Techniques based on formal mathematical methods and computer technology, though being unable to completely resolve these issues, bring new data to the discourse of musicology and art.**

Keywords–Musicology; music information retrieval; human-centric computing; music similarity; pattern matching; music signature; music modeling.

I. Introduction

In [1], in the scope of a conceptualization of the analysis of Pyotr Tchaikovsky's "Children's Album" (Op. 39) with the use of computational models, an approach based on David Cope's signatures [2][3] is sketched as a promising way to help musicologists in resolving a number of riddles posed by Tchaikovsky in his famous cycle of 24 piano pieces thought to be for children. The analysis of possible sources, metaphors, and renditions of this masterpiece originally published as far as in 1878 by Yurgenson [4] still remains a constant topic of interest for researchers [5][6]. While admitting Schumann's influence on Tchaikovsky (along with other precursors, such as Bach, Mozart, Beethoven, Chopin, or Berlioz), there is still a challenging question on whether we have to completely accept the author's claim that the compositions from the "Children's Album" are a form of imitation of Schumann's pieces for the young [7], even with respect to the subtitle appeared in the first published edition by Yurgenson: "Simple pieces for children *(imitating Schumann)*" (Figure 1*(a)*). Interestingly, such a subtitle is missing in the manuscript [8], though the latter is a fascinating example of the accurately presented and organized hand-written work (Figure 1*(b)*).

Unlike Tchaikovsky, from the outset Schumann had not intended for his collection of compositions for children to be a seamless large work, finally organized as Op. 68. Indeed, he initially composed 10 pieces considered as nice exercises for his own children, and even though he announced its completion, more pieces appeared later, in 1848. By composing the exercises which would be nicer than most things that children normally needed to play during their piano studies, Schumann "not only revolutionized attitudes concerning music education, but also inaugurated an entirely new genre of piano literature – programmatic music written explicitly for children" [9]. The latter facts do not contradict the idea that Tchaikovsky could still have wished to imitate Schumann's approach, though musicological analysis of his Op. 39 usually debates this hypothesis much.



(a) Subtitle "imitating Schumann"

(b) Fragment of No. 5 "March of Wooden Soldiers" immediately followed by No. 6 "A New Doll" on the same sheet

Figure 1. Cover of the Yurgenson's edition and a fragment from Tchaikovsky's manuscript.

The remaining text is organized as follows. Section II provides an introduction to the concept of signatures according to Cope. In Section III, we describe a case study on signature elicitation for Tchaikovsky's "Children's Album". To conclude, we summarize the most important insights on how the formal approach we used can be beneficial for musicology experts. We also sketch necessary extensions that can improve the accuracy and veracity of the applied computational models.

II. Music Signatures by Cope

Signatures form one of the core elements of music representation and automatic generation system developed by Cope [2][3], which uses an implementation of augmented transition network, a finite-state automaton with recursive succession rules between music sub-phrases allowing for logical syntax substitutions [10].

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Cope defined a *signature* as a set of contiguous intervals found in more than one work by the same composer [11]. Typically, a signature is composed of two to nine notes (or more, if combined with harmonies). The idea of signature is to represent a composition-independent pattern, which does not sound as an excerpt from a particular work, but rather represents a characteristic description of one of composer's style elements.

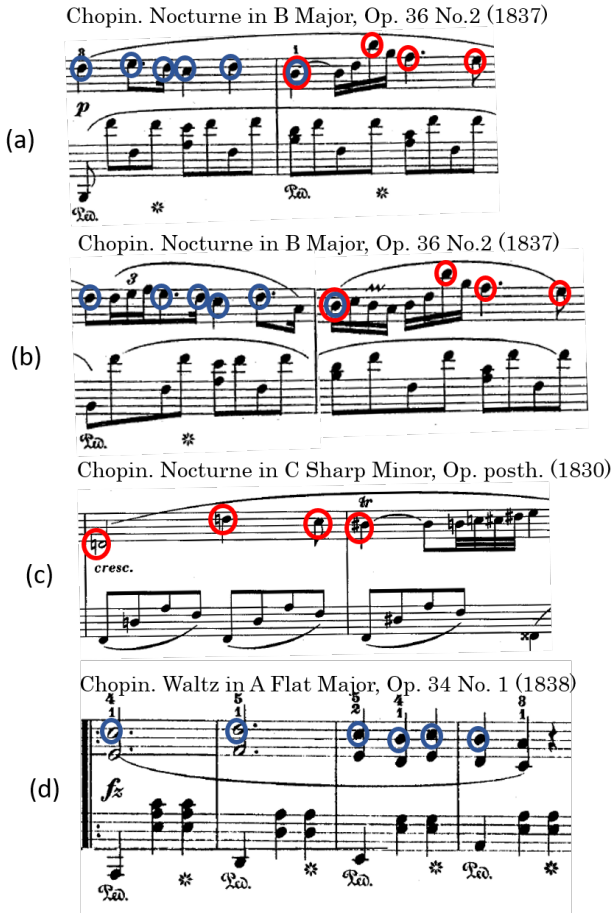

Figure 2. Possible signature candidates from Chopin's compositions.

Signatures portray patterns combining melody, harmony and rhythm information, with possible **transformations** of interval, pitch, rhythm and voice exchange. Even transformed, the patterns can still be recognised by ear. Figure 2 shows two examples of possible pattern candidates coloured red and blue along with their transformations in the works of Chopin.

As we can see from the examples in Figure 2, many significant patterns need to be detected approximately, not exactly. Cope compares the pattern matching fine-tuning process to the sieving the candidates through a mesh. The sieving process controls the *granularity* of allowed pattern transformations enabling inexact pattern matching. Cope introduced a number of parameters – controllers. The controllers help to establish pattern matching thresholds to work with variances and be able to find signatures, which are not identical, but are musically comparable. For example, if we set the maximum number of notes in the target pattern too small, the discovered patterns might be too short to be sufficiently reflective (though, some harmonic cadence signatures can be short enough). If we set the value of the same parameter too high, the resultant output can be too specific to a particular composition, and again, unreflective of a composer's style in general. To illustrate the concept, there is a list of some examples of controllers as defined by Cope [12]:

- `allowance` – defines the possible deviation of the melody in half steps (see example with the red patterns in Figure 3).
- `contour` – defines how much the general contour of two fragments conforms to each other (see the cases *(b),(c)* in Figure 4).
- `inversion` – looks for patterns with inverted sequences of notes (or intervals).
- `interpolation` – allows for intervening notes (see the cases *(a),(b)* in Figure 2).
- `pattern-size` – defines the size of pattern selected for comparison.
- `rhythm` – determines whether the patterns match because of rhythmic match only (like in many genre pieces, such as dances, where the rhythm is a significant component of the style).

Reusing a signature of one composer in the work of another author (often with recombination and variations) could create allusions to appear as a more sophisticated construction rather than straightforward borrowing of melodies or motifs.

In Figure 3, we can see the analysis demonstrating an exact pattern reuse (shown in blue), as well as possible inexact variation (shown in red). In the latter case, typical pattern with a sub-melody often appearing in the second voice of Chopin's piano composition, also used by Adam with a slightly transformed sub-melody (shown using a dashed line).

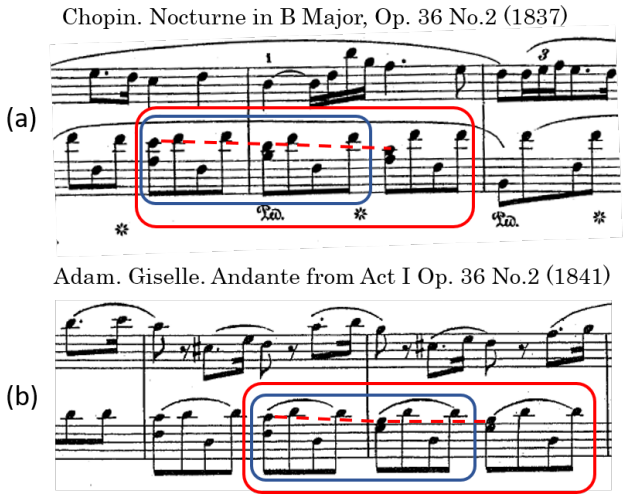

Figure 3. Similar patterns in the works of Chopin and Adam.

Figure 4 illustrates pattern elicitation in Chopin's Waltz in C Sharp Minor *(b)*, which can be inexactly matched to the pattern found in Griboyedov's Waltz in E Minor *(a)*. The latter work contains the pattern *(d)* matching (with slight transformations) the fragment from the part 2 of Mozart's piano concerto No. 23.

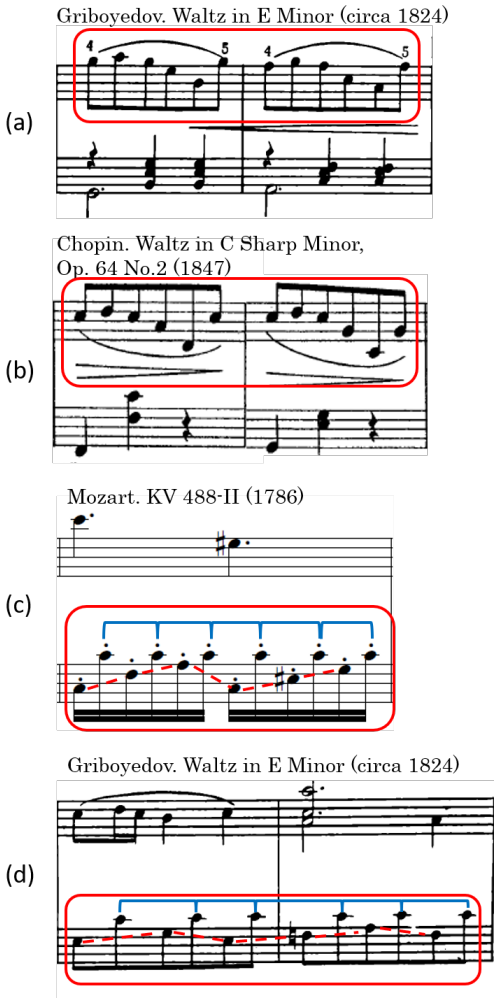

Figure 4. Examples of inexact pattern matching in the works of Mozart, Griboyedov, and Chopin.

Pattern matching methods based on signature elicitation can be applied to authorship identification, along with other known approaches, such as analysis and modeling of music structure using N-grams [13][14], Markov chain models [15][16], deep neural networks [17][18], analysis of high-level music features like counterpoint structures [19], grammatical inference [20], and cortical algorithms [21]. However, signatures are not only helpful for authorship attribution, but also for in-depth analysis of music compositions to discover the characteristics of style, their genesis, and their development. The links between the authors and the periods may also be identified, which will be of great interest for musicologists.

III. "Children's Album" as a Test Bed for Signature Elicitation Algorithm

In this section, we describe a case study on applying the signature elicitation software to obtain new data showing the links between the compositions from "Children's Album" and the works of other composers that influenced the style of Tchaikovsky.

A. Software

The signature discovery process was organized using the software we developed [22] based on Cope's algorithms adapted to the present-day standard music analysis tools available in numerous Python libraries. Notably, in order to parse and analyze input files in different formats (like MIDI and KERN) we are using `Music21` [23] – an open source library for computer-aided musicology created and supported by the the Music and Theater Arts Section, MIT.

The software we developed accepts pairs of *(file,author)*, where the file contains notated music in symbolic formats like MIDI [24] or KERN [25]. Since the source file usually contains polyphonic music, the preparation step is to extract the melody (we use Skyline[26]-like algorithm).

The next stages of the workflow are as follows:

1) In each *single* composition, find the patterns appearing 5 to 12 times. These patterns are considered as signature candidates.
2) Collect the candidates across the different available works of the given composer.
3) From the complete list of collected patterns, eliminate the patterns that do not appear often enough (i. e., in less than 10% of all the analyzed works of the same composer).
4) Compare the found patterns against the patterns of different composers and eliminate the patterns, which are frequently used by other composers, as such patterns that appear to characterize the epoch rather than a particular composer's style.

As a result of the above-described procedure, there is a database of signatures considered to uniquely characterize each single composer (at least, within the context of the given dataset), along with additional metadata, such as the location of signatures in the original works.

We used our software in the experiments with the composer identification task (to be discussed in the separate publication), and found that the signatures can be used to reliably identify composers in many cases. In terms of *success rate*, the achieved results are comparable to some well-known approaches such as Markov chains (giving a rate of 75%), but not so fine-grained compared to the best approaches demonstrating up to 90% success rate.

As a side result of these experiments, we built a database containing the characteristic signatures of Bach, Beethoven, Haydn, Mozart, Vivaldi, and others, extracted from a dataset containing over 100 works of each author.

B. Data

With respect to the goals of this case study, our training set was constructed using 90 compositions by Tchaikovsky, and 61 works by Schumann (including those from the Album for the Youth, Op. 68). Thus, we used an input dataset of 151 works in total, to extract signatures of both composers, and extend the collection of found signatures with the signatures of other composers, which became available due to the process of evaluating our software for signature based composer identification. Adding the signatures of other composers can be helpful in filtering the output so as to discard patterns that may be attributes of period or genre rather than of particular composers.

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Our target testing set included all the 24 piano pieces from Tchaikovsky's "Children's Album".

C. Experiment at a Glance

For this experiment, we used a database of more than 26485 signatures in total (including variations). The database was filtered by eliminating 11745 duplicates that can be found in the works of different composers. The resulting log is available at https://github.com/andrei-kuznetsov/signatures/files/9377147/signatures-wo-dupplicates.txt.

TABLE I. SIGNATURES FOUND IN TCHAIKOVSKY'S "CHILDREN'S ALBUM"

Composer	Acronym	Signatures (including variations)	Compositions
Tchaikovsky	TCH	19	13
Haydn	HAY	20	8
Beethoven	BEE	9	8
Mozart	MOZ	8	7
Vivaldi	VIV	13	5
Bach	BAC	1	1
Schumann	SCH	5	3

TABLE II. SIGNATURE DISTRIBUTION

No.	TCH	HAY	BEE	MOZ	VIV	BAC	SCH	Total
1					1			1
2	1		1	1				3
3	1						2	3
4	1		1					2
5								0
6	1	1			1			3
7			1					1
8		1						1
9	1	3	1	2	2			9
10				1				1
11	1			1		1		3
12		1					1	2
13			1					1
14	4			1				5
15			1	1				2
16		1						1
17		3	2					5
18		9	1	1	3			14
19	3							3
20								0
21	2							2
22	1				6		2	9
23	1							1
24	3							3
All	**19**	**20**	**9**	**8**	**13**	**1**	**5**	**75**
All*	**18**	**11**	**8**	**7**	**4**	**1**	**3**	**52**

* excluding No. 18 and No. 22, where disproportionately big number of signatures of one composer is found compared to others

Table I lists the cumulative results of signature elicitation process. For each composer, we show the total number of signatures found and the number of compositions in which the signatures were discovered. Here and after we use the composition numbering according to Tchaikovsky's manuscript [8]. Table II shows the distribution of signatures among all the compositions.

Based on the analysis of *All* row from Table II, we could suggest that the results of automatic signature elicitation process need to be corrected with further elimination of some repeated signatures based on manual expertise of music files with marked up signatures (e.g., using *MuseScore* software). For example, in the compositions No. 18 "Neapolitan Song" and No. 22 "Lark's Song", there is a definitive disproportion between the signatures of one composer against the signatures of others. It can be explained by the fact that in these compositions notably we can find a lot of small repetitive (but not always completely equal) patterns (as shown in Figure 5) that could lead to signature over-count.

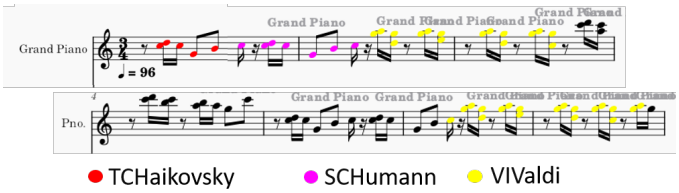

Figure 5. Repeating patterns in No. 22 "Lark's Song".

D. Preliminary Analysis

Schumann signature variations are only found in 3 compositions: No. 3 "Mama" (2 cases), No. 12 "Russian song" (quite surprisingly perhaps), and No. 22 "Lark's Song" (2 cases). We can also see that in all these cases the characteristic signatures of Schumann appear along with other signatures, particularly, in No.22, when, in addition to those of Schumann, we discovered 7 signatures of other composers.

From the experiments with the signature database, we learned that the recognition rate for particular composers is unstable and ranges between around 50% to 80% . Even if we acknowledge that some unique Schumann signatures were missed due to the imperfectness of automatic signature elicitation process, we can still argue that compared to other discovered signatures, there is a very low number of Schumann's cases. Though, in concordance with Cope's definition, an imitation of style does not assume appearance of signatures of the imitated composers, their very rare occurrences provide a rationale for disputing the possibility for deliberate imitation of Schumann's style by Tchaikovsky.

IV. Discussion

The question of attributing Tchaikovsky's masterpiece as an imitation of Schumann is important as a part of the broader challenge: to approach possible explanations on why we find so many disruptive transformations in the first published edition compared to the so accurately prepared manuscript. Figure 6 illustrates the transformations related to the order of compositions. Since if we can provide a good rationale for understating the author's claim on imitation, we can also call into question the meaningfulness (or rather meaninglessness) of those transformations destroying the structure of the album as an indissociable whole, and deforming the micro-cycles and internal links existing in the manuscripts [27][28].

So far, the studies of the above-mentioned questions mostly remained in scope of music and art theory, with almost no involvement of computational approaches to music analysis. Techniques incorporating the formal mathematical methods and computational approaches could not (fortunately) completely resolve these questions *ex cathedra*; however, they could produce a number of important additional insights to the problems usually addressed exclusively from the musicology and human science positions.

As mentioned earlier [1], one could hardly accept an idea that the alteration of numbers, which led to destruction

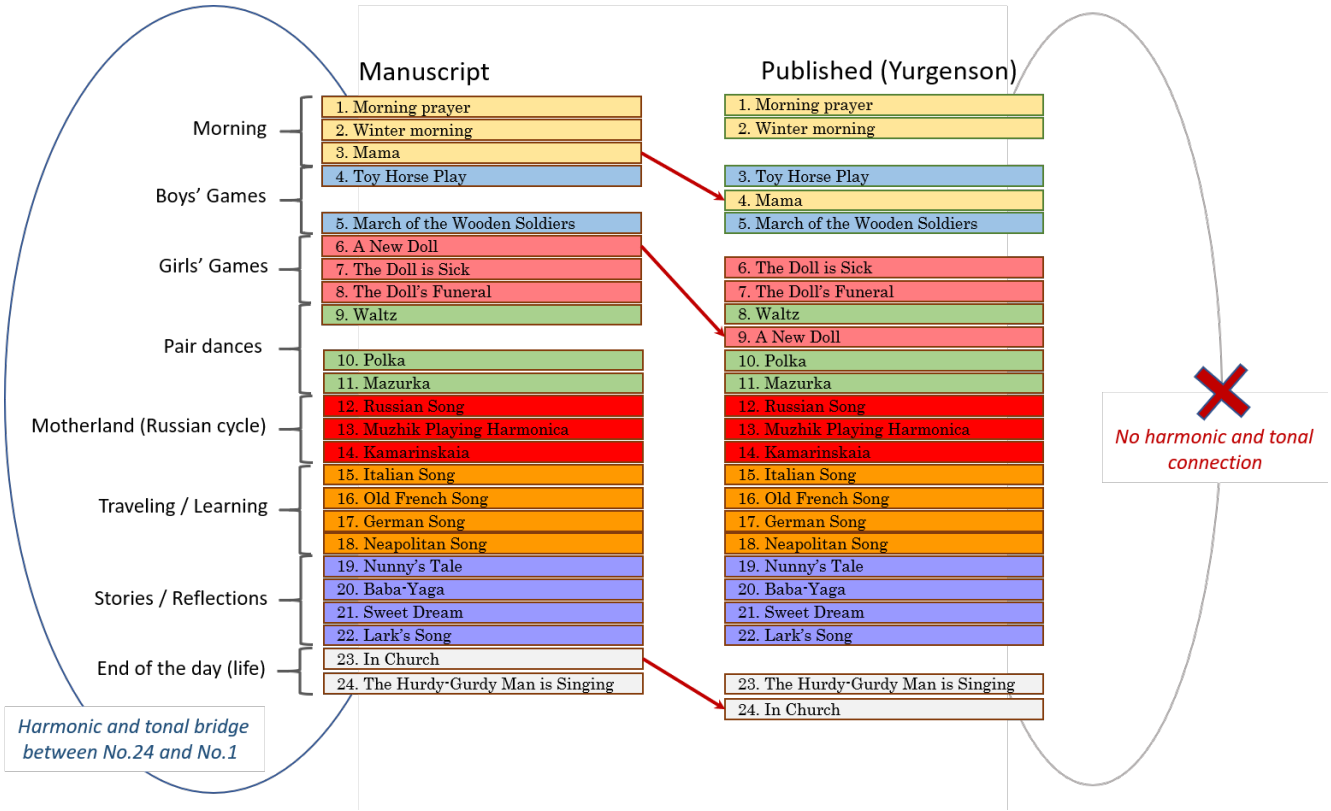

Figure 6. Order of compositions and micro-cycles in "Children's Album".

of junctions between the pieces existing in the manuscript, was a publisher's mistake. Indeed, Tchaikovsky approved and signed that version. Nekhaeva suggested that these serious transformations (partially shown in Figure 6) can be interpreted as a "gesture of the composer, a natural desire to overcome the temporary barrier and directly appeal to future generations of musicians" [6]. This opinion supports a hypothesis claiming that Tchaikovsky probably preferred to simplify the language and to decrease the emotional tension of the original version, and, in so doing, to hide some metaphors, to make them less explicitly exposed. The author's explicit claim on imitating Schumann's approach could be understood being in line with the above mentioned simplifications and transformations. Therefore, by raising the arguable doubts on this declared imitation, we can support the analysis of appropriateness of the discussed transformations as well, and, actually, vice versa.

V. Conclusion

The novel results we obtained from our preliminary experiments are very interesting, though not sufficient, and need to be reexamined after extending the dataset with respect to the following important types of input:

- Compositions with expected high degree of style similarity, which were attributed by their authors as imitations; and
- Characteristic compositions (e.g., by Tchaikovsky), where style similarity was reported by musicology experts.

The studies [29][30] can provide information for selection of relevant referential datasets necessary to improve the accuracy of the signature based music pattern recognition process.

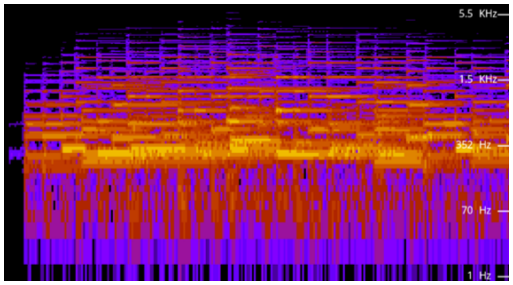

Figure 7. Sample spectrogram of "A New Doll" on a logarithmic scale (Op. 39, orig. No. 6) created using Spectrum Analyzer [31].

It is worth noting that the discussed signature elicitation models do not oppose an idea to use machine learning approaches to music style identification. On the one hand, we already mentioned a number of deep learning methods suggested by different researchers for author identification and style recognition. These models often work with the input represented in the form of spectrograms (similar to one shown in Figure 7).

Though there are many challenges in constructing an explainable machine learning algorithm producing the results and making conclusions that can be understood by musicologists, the possibility to apply such approaches to our problem need to be investigated in more depth. On the other hand, the process of signature discovery itself can be implemented using machine

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learning (e.g., CNN as the most common possible solution). Such an implementation surely would be an interesting option for further explorations. However, though not novel, the semi-automated approach based on Cope models, can still be relevant to our study for a number of important reasons:

1) Rather then asking a question of author or style attribution, we are searching for the structural elements that can be understood by music experts and enhance their knowledge on the genesis and development of music style in the work of a particular composer (e.g., Tchaikovsky).
2) With respect to the possibility to develop or use machine learning algorithms (including those applied to the process of signature elicitation), one needs to have ground truth information that, as we believe, can be delivered based on "adjustable machine-oriented models", such as those described by Cope.
3) In contrast to signatures defined using music notations (e.g., music scores) and representations (e.g., MIDI), and, therefore, can be directly analyzed and perceived by music experts, machine learning features, coefficients, and probability distributions are definitely less favorable to humans.

We admit that playing with pattern matching settings and further adjustments of the signature elicitation algorithms might affect the specific signature scores we obtain from these algorithms. However, our preliminary experiments demonstrate that the relative distribution of signatures between different composers does not fluctuate too heavily upon the changes in pattern matching controlling parameters; thus, making our qualitative judgements well-reasoned, though not conclusive.

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