Digitizing a 19th-Century Music Theory Debate for Computational Analysis

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Abstract

We report the progress of the ongoing project "Digitizing the Dualism Debate: a case study in the computational analysis of historical music theory sources". First, we give a brief introduction to the dualism debate, a central discussion in 19th-century German music theory. We then describe the transcription pipeline with which we process the digitized sources in order to arrive at a corpus of computationally feasible representations, and discuss a number of encountered challenges, e.g. the assignment of structural types and idiosyncratic symbols. Employing text similarity measures and topic modeling, we present some preliminary analyses. Future steps include text annotation, music encoding, and the presentation of the corpus with an online interface.

Keywords

digital musicology, music theory, dualism debate, corpus study, computational humanities

1. Introduction

We present the ongoing project "Digitizing the Dualism Debate: a case study in the computational analysis of historical music theory sources" that strives to reconstruct and critically evaluate the discursive relations within this debate by harnessing the combined power of qualitative-historical and quantitative-numerical methods. The "dualism debate", a hot topic in 19th-century German music theory [30, 17], is concerned with the mutual relationship of major and minor triads. Specifically, the discussion revolves around whether the minor triad is a mere derivative of the major triad (the monist position, e.g. by lowering its third by a semitone) or whether it can be derived from first principles on its own right (the dualist position, e.g. by postulating the existence of an undertone series) [15, 35, 6, 20, 12, 37]. By negotiating the relationship of Western music's two most relevant qualities of chords, and by extension their scales and tonalities, the debate concerns the most fundamental level of how harmony is conceptualized theoretically. Authors thus put forth their ideas in thorough and at times passionate ways, while drawing from different scholarly backgrounds (e.g. acoustics, physiology, practical harmony, or philosophy). Although the historical debate has essentially been settled [26, 5, 16], it still resonates in more recent approaches to harmony [10, 8].

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Table 1
Overview of the transcribed sources (see References for full titles). Note: the total number of types is not the sum of the number of types for all texts since the vocabularies overlap.

Author	Year	Pages	Types	Tokens	ID	Ref.
Moritz Hauptmann	1853	394	7'511	33'938	HAU1853	[11]
Ernst Naumann	1858	52	2'662	7'252	NAU1858	[23]
Carl Friedrich Weitzmann	1860	63	1'788	4'853	WEI1860	[40]
Carl Friedrich Weitzmann	1861	28	1'677	3'050	WEI1861	[39]
Franz Joseph Kunkel	1863	59	5'193	13'408	KUN1863	[18]
Arthur v. Oettingen	1866	294	6'463	25'045	OET1866	[25]
Adolf Thürlings	1877	51	3'279	6'454	THU1877	[38]
Hugo Riemann	1905	36	2'269	4'136	RIE1905	[31]
Georg Capellen	1905	88	4'753	12'373	CAP1905	[4]
Total		1'065	20'436	110'509		

We address our project aims by creating a corpus for computational analysis from relevant sources. The current state of the project and the following descriptions and analyses are based on a sub-corpus of nine selected core texts. The selection comprises eight authors and more than a thousand pages of text (see Table 1). The texts following and including von Oettingen's "Harmoniesystem in dualer Entwicklung" (1866) have dualism as their primary focus, whereas the earlier texts feature and develope such ideas in a more implicit manner, i.e. without using the term "dual". Containing texts published between 1853 and 1905, the corpus may give some indication of how the discourse changed over time and eventually became a debate. Some texts are also directly responding to others in the corpus, thus forming meaningful connections within it. Other full texts as well as particularly relevant excerpts from other sources will follow in due course. Scans of the chosen works were either available from various online resources or requested from libraries.

In this paper, we provide an overview of the transcription pipeline, consisting of segmentation, OCR transcription, corrections, and export using the transcription tool *Transkribus* [22]. We describe a number of challenges particular to our corpus and report some initial computational analyses, namely text similarity and topic modeling. Finally, we discuss future steps, such as annotation, music encoding, and presentation of the project online. By creating a machine-readable resource of historical texts and applying methods from digital humanities, our project aims at bridging the gap between the humanities and the sciences, in particular music theory and corpus studies [24], and at providing a case study for how computational analysis can be fruitfully employed in musicology.

2. The transcription pipeline

2.1. Segmentation

During the segmentation process text regions and other elements on the page were identified and labeled according to their content type and function within the text. Since we are interested in representing the logical structure of the text, and not the physical book, it was important to distinguish whether a paragraph or graphic is completely shown on a page, or is continued on a different page. This allows us to reconstruct the precise beginnings and endings of units,

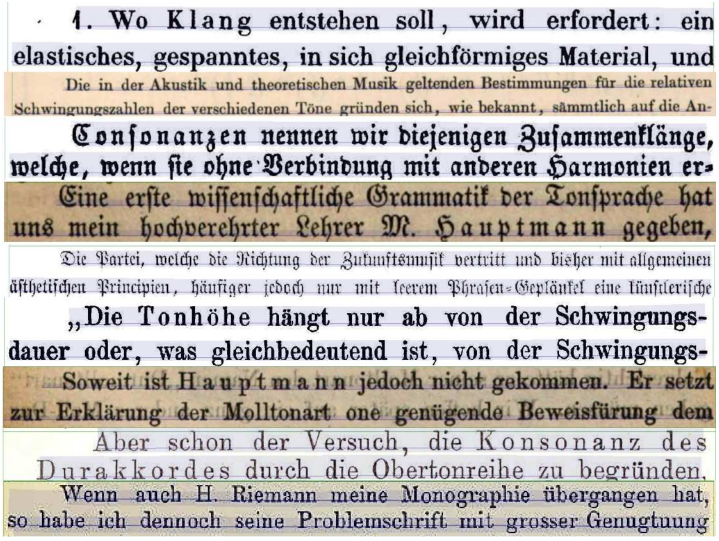

1. Wo Klang entstehen soll, wird erfordert: ein
elastisches, gespanntes, in sich gleichförmiges Material, und
Die in der Akustik und theoretischen Musik geltenden Bestimmungen für die relativen
Schwingungszahlen der verschiedenen Töne gründen sich, wie bekannt, sämmtlich auf die An-
Consonanzen nennen wir diejenigen Zusammenklänge,
welche, wenn sie ohne Verbindung mit anderen Harmonien er-
Eine erste wissenschaftliche Grammatik der Tonsprache hat
uns mein hochverehrter Lehrer M. Hauptmann gegeben,
Die Partei, welche die Richtung der Zukunftsmusik vertritt und bisher mit allgemeinen
ästhetischen Principien, häufiger jedoch nur mit leerem Phrasen-Geplänkel eine künstlerische
„Die Tonhöhe hängt nur ab von der Schwingungs-
dauer oder, was gleichbedeutend ist, von der Schwingungs-
Soweit ist Hauptmann jedoch nicht gekommen. Er setzt
zur Erklärung der Molltonart one genügende Beweisfürung dem
Aber schon der Versuch, die Konsonanz des
Durakkordes durch die Obertonreihe zu begründen,
Wenn auch H. Riemann meine Monographie übergangen hat,
so habe ich dennoch seine Problemschrift mit grosser Genugtuung

Figure 1: Sample lines from each of the documents in Table 1 (in order), illustrating the variety in font-styles and scan quality present in the corpus.

regardless of page breaks. Errors on the baseline level may result from the splitting of text regions, it was therefore crucial to examine the lines after the region segmentation, to ensure that all lines within text regions were represented correctly and in the right order.

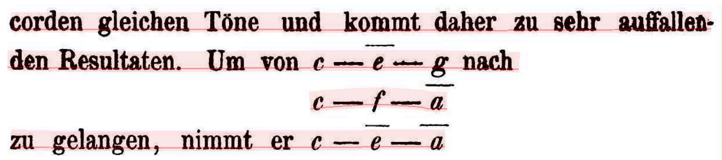
2.2. OCR transcription

Subsequently, the entire document was first transcribed using AI-powered *Optical Character Recognition* (OCR) built into Transkribus. Several OCR models are available, each more or less specialized for specific scripts, languages, and source types. Our corpus is quite diverse in terms of font face, style, and scan quality (see Figure 1), but reasonably homogeneous from a linguistic perspective: all texts are written in German and stem from a narrow period of roughly 50 years. The following setting has proven to be a good choice for automated transcription on all documents transcribed thus far: `CITlab HTR: ONB_Newseye_GT_M1+`, `Dictionary: trainDataLanguageModel`. This model was trained in the *NewsEye* project [7] on newspapers in German from the late 18th to mid 20th century, taken from the Austrian National Libraries ANNO Collection.[1] They comprise mostly black letter (Fraktur) but also Roman fonts and thus by and large historically and typographically resemble our corpus.

2.3. Corrections and export

The text produced by OCR was then subjected to careful review by a native German speaker with good understanding of music theory. For normal sentences, relatively few mistakes had to be corrected overall. The OCR performance on Roman fonts was slightly worse than on black letter, but still highly satisfactory for an initial transcription. However, specialized expressions such as note names or harmonic analyses had to be reproduced by hand, all emphases had to be added manually, and some aspects of the transcribed texts had to be edited in accordance

[1] https://anno.onb.ac.at/



corden gleichen Töne und kommt daher zu sehr auffallen-
den Resultaten. Um von c — $\overline{e}$ — g nach
c — f — $\overline{a}$
zu gelangen, nimmt er c — $\overline{e}$ — $\overline{a}$

Figure 2: Screenshot from a source page. The text flows around the chord spellings, which are set to vertically align with each other.

to our *editorial guidelines*,[2] which are updated and refined throughout the project. For most aspects (i.e. spelling, modes of emphasis), the guidelines aim to reproduce the text as it appears in the original source. However, some aspects, such as font face, quotation marks, and hyphens, were unified for practical considerations. Finally, the transcriptions were exported to the XML format of the *Text Encoding Initiative* (TEI) [13] as well as simple text for further processing and computational analysis.

3. Challenges

3.1. Distinguishing between graphic and text

Music-theoretical treatises present a challenge to corpus linguistic approaches because the authors do not only express themselves in natural language, but also use abstract, often highly idiosyncratic symbols to designate musical concepts and relationships. The first problem this poses is that symbols may not be easily represented using the means available in Transkribus. In some instances, such as for lines written above or below note names, alternative notations had to be invented. Analytical expressions may also exist on a gradient between text and graphical content: Whereas a simple chord spelling like C - e - G can be understood as regular text, the addition of brackets, arrows or specific alignments may make it a graphic.

Some music theorists may traverse quite flexibly between the use of natural language and symbolic illustrations, for example by introducing specific alignments into their text, which blur the line between a graphical and non-graphical use. This results in formations which might be quite readily understood by a human reader, but are difficult to represent and label appropriately in a digital format. An example of this is shown in Figure 2. Another frequent occurrence is that the graphical illustrations, although spatially separated from the text, are still embedded in the same sentence structure. This means that the sentence becomes incomplete on the main text level, if words in the graphic are excluded.

3.2. Unrepresentable means of highlighting

By far the most common mode of emphasis in the sources is letter space, followed by bold and italics. These are easily reproduced using Transkribus' interface. For other modifications, namely text alignment and font changes, this does not apply. Being centered may lead to interpreting a mathematical or analytical expression as a *floating* element. For a centered sentence, however, it is not desirable to label it as a float and thereby exclude it from the text proper, so we may treat it as a normal line within the paragraph, which removes some of the emphasis but keeps the text intact. Especially in texts set in black letter, authors

[2] https://github.com/DCMLab/ddd/wiki/Editorial-Guidelines

sometimes chose to set foreign terms or note names in Roman font, distinguishing them from their surrounding. Due to their subtle nature we ultimately decided to not take font changes into account.

3.3. Other issues

1) The editions we used for `KUN1863` and `HAU1853` feature errata pages. Although this project does not aim to produce scholarly editions of the texts, we chose to adjust simple spelling or grammar mistakes. Corrections within graphics pose a problem as we intend to take graphics directly from the text. It was also not practically feasible to implement corrections referring to general oversights by the publishers. 2) Hauptmann makes extensive use of musical notations, which contain only rhythmic information, but no lines indicating pitch. We eventually decided to limit the label 'music' to examples which are written on a staff with five lines. The rhythmic notation in `HAU1853` is thus labeled as a graphic instead. 3) Kunkel uses two levels of footnotes. Since this is unique to this text, the hierarchical relationship is represented by the symbols used, not by a special structure type. 4) `WEI1861` contains dashes that do not appear to posses any syntactical significance. They have been left in the text because their meaning yet unclear, with one hypothesis being that they represent an omission, e.g. by censorship or editorial digression.

4. Preliminary analyses

The 9 texts by 8 authors comprise 1'065 pages, 110'509 word tokens, and 35'595 word types in total (without stop words). Besides text, they conjunctly contain 402 music examples (384 floating, 18 inline), 829 graphical elements (720 floating, 138 inline), and 22 tables. We used the `spaCy` library for basic text processing.[3] Overall, the ten most frequent nouns are 'Töne' (675), 'Ton' (450), 'Terz' (446), 'Bedeutung' (420), 'Folge' (410), 'Tonart' (364), 'Grundton' (355), 'Accorde' (289), 'Dissonanz' (272), and 'Dreiklang' (249), clearly reflecting their music-theoretical focus. In this early phase of the project, we did not yet apply more refined NLP strategies such as lemmatization (e.g. merging singular and plural forms of nouns) but focus on two computational analyses on the 'raw' word counts, namely *text similarity* and *topic modeling*, which will form the basis for more extensive textual explorations in future research.

4.1. Lexical text similarity

To assess their lexical similarity, we compute vector representations of all texts by weighting the respective word counts with *term frequency-inverse document frequency* (TF-IDF) [33] after removing custom stop words, and use *Principal Components Analysis* (PCA) [14] for a reduction to two dimensions (left of Figure 3); we rely on the algorithms provided by the library `scikit-learn`.[4] One can observe that the texts group into two clusters that are separated by the first principal component: 1) `WEI1860`, `WEI1861`, and `KUN1863`, and 2) `HAU1853`, `NAU1858`, and `OET1866`, as well as `THU1877`, `RIE1905` and `CAP1905`. Moreover, within the second cluster, one can observe a diachronical trajectory where the second principal component distinguishes earlier from later publications. However, rather than representing historically changing language style, the clusters reflect kinship in content: Naumann was a student of Hauptmann

[3] https://spacy.io/
[4] https://scikit-learn.org/stable/

and dedicates his work to his teacher; both Hauptmann's and Naumann's texts are referred to in the introduction of Oettingens's book and he considers his achievement to be the conjunction of Hauptmann's and Helmholtz's teachings.[5] Thürlings' work features extensive reviews of Hauptmann, Helmholtz and Oettingen, while preparing some of the ideas later discussed between Riemann and Capellen. It thus connects these two groups of works.

However, textual similarity as expressed by the TF-IDF vectors does not always correspond to positive affinities: `KUN1863`'s proximity to Weitzmann's texts can be explained rather by strong and direct opposition than by positive reference; e.g. his *Kritische Beleuchtung* accuses Weitzmann of "error, ignorance, or intentional disregard" of prior literature [18, subtitle]. Likewise, `RIE1905` and `CAP1905`, the youngest two texts in our corpus, are relatively similar in terms of their term frequencies, but could not be more contrasting in terms of their intention. Riemann's text is decidedly 'dualist' and meant as a concise summary of his earlier extensive writings on the topic and Capellen's direct reply vehemently defends 'monism'. On the other hand, `WEI1860` and `WEI1861` are relatively distant, although they have the same author and topic, and are published in consecutive years.

The data variance explained by the first two principal components are 29.9% and 15.5%, respectively, together accounting for less than half of the entire variance. Further analyses and pre-processing steps are thus required for a deeper understanding of the textual similarities in our corpus.

4.2. Topic modeling

Topic modeling, in particular with *Latent Dirichlet Allocation* (LDA) [1], is a widely-adopted technique in the digital humanities [2, 28, 21]. Here, we rely on the the implementation of `tomotopy`[6] and retrieved the 5 most likely topics for our corpus. Table 2 lists the 15 most common words per topic along with their TF-IDF-weighted frequencies, Table 3 shows the distribution over topics for each text, and the right panel of Figure 3 shows a PCA reduction of the topic vectors, where their size inversely corresponds to their *topic coherence* [36].

Topic 1 features chord-related terms such as 'Folge' (sequence), 'Terz', 'Quint', and 'Grundton', (third, fifth, and root; the constituent tones of triads), as well as 'Dreiklang/Dreiklänge' (triads), and we designate this topic with "chords". Topic 2 likewise contains the notions of 'Terz' and 'Quinte', but the presence of 'Octave' as well as of 'Intervalle', 'Obertöne', and 'Schwingungszahlen' (intervals, overtones, and frequencies), and 'Helmholtz', indicate that they signify intervals in the acoustic sense instead of chord tones. We thus call this topic "acoustics". Topic 3 prominently features all notes of the C-major scale except (plus 'b' and 'fis', the German versions of b♭ and f♯), and could be termed the "tones" topic. Topic 4 appears particularly Hauptmannian: unity ('Einheit') is one of the core notions of his dialectic/dualistic theory, and half of his book is concerned with meter, reflected in terms such as 'Metrum'n, 'Ordnung', 'metrische(n)', and 'Form' (meter, order, metrical, and form), and this topic can thus be called "meter". Finally, Topic 5 appears mixed and less coherent than the others. It features music-theoretical vocabulary ('Tonart', 'Akkorde', 'Harmonie', 'Theorie', 'Musik') as well as book-related words ('Verfasser', 'Beispiele', 'Erklärung'). In lack of a better term we designate it with the very general label "music theory".

The topic distributions in Table 3 indicate a relatively strong correlation between certain texts and topics: all texts feature one or two particularly strong topics. This might be partially

[5] The latter are not part of the present version of the corpus.
[6] https://pypi.org/project/tomotopy/

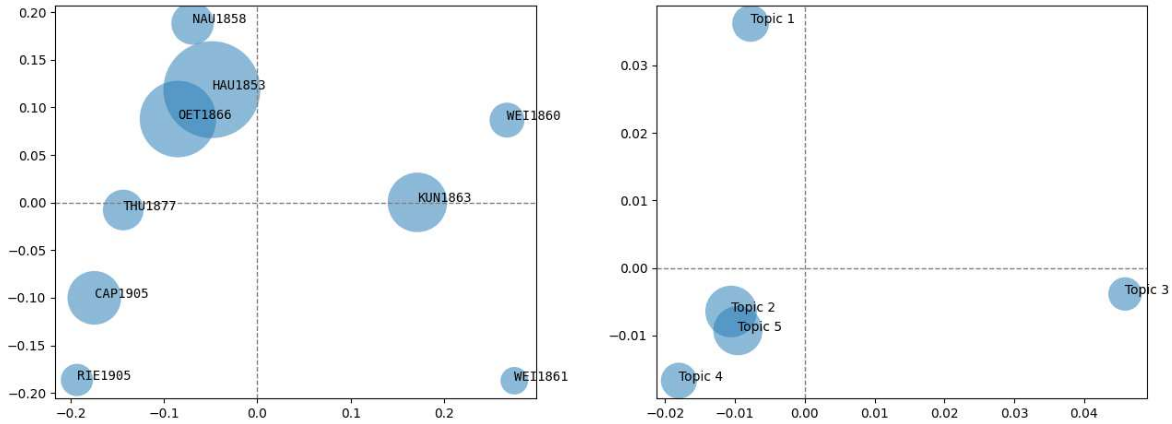


Figure 3: Similarities of texts and topics. Left: PCA reduction of TF-IDF vectors of the eight sources; circle size is proportional to text length. Right: PCA reduction of five topics; circle size is anti-proportional to topic coherence (less coherent topics are displayed larger).

Table 2
15 most common words and their TF-IDF-weighted frequencies (in %) for all 9 texts and 5 topics.

Topic 1 (“chords”)	Topic 2 (“acoustics”)	Topic 3 (“tones”)	Topic 4 (“meter”)	Topic 5 (“music theory”)
Folge (1.08)	Töne (1.29)	c (2.76)	Einheit (1.28)	Verfasser (0.51)
Terz (1.08)	Intervalle (0.7)	g (2.1)	Bestimmung (1.14)	Theorie (0.49)
Quint (1.06)	Terz (0.59)	e (1.8)	Ordnung (0.8)	Tonart (0.47)
C (1.03)	reinen (0.52)	d (1.57)	Metrum (0.78)	Harmonie (0.45)
Grundton (1.01)	Musik (0.51)	a (1.44)	Bedeutung (0.76)	Musik (0.39)
Tonart (0.95)	Ton (0.48)	f (1.4)	metrischen (0.71)	Töne (0.38)
Dreiklang (0.89)	Obertöne (0.45)	h (1.06)	Glied (0.7)	Accorde (0.37)
Auflösung (0.83)	Octave (0.42)	C (0.72)	metrische (0.6)	Tonarten (0.35)
tonischen (0.82)	Helmholtz (0.4)	Klänge (0.7)	Form (0.55)	Beispiele (0.33)
Ton (0.82)	Schwingungszahlen (0.38)	Verwandtschaft (0.6)	Bestimmungen (0.54)	Lehre (0.33)
Accorde (0.76)	nämlich (0.38)	phon (0.6)	Quint (0.5)	alten (0.33)
Töne (0.75)	Quinte (0.37)	phonischen (0.54)	Folge (0.49)	lassen (0.3)
G (0.74)	Reihe (0.37)	b (0.51)	Momente (0.49)	Quinten (0.3)
Dreiklänge (0.73)	musikalischen (0.36)	Ton (0.49)	Formation (0.49)	Harmoniesystem (0.29)
Bedeutung (0.72)	Konsonanz (0.36)	fis (0.48)	lassen (0.49)	Erklärung (0.28)

due to different conventions in notation (e.g. of tones and chords) and terminology, but also reflects some of the thematic differences discussed above (e.g. Hauptmann’s stronger metrical focus, Kunkel’s direct reference to Weitzmann, and Capellen’s reply to Riemann). A factor that needs to be addressed in our future analyses is the impact of text length: Hauptmann’s and Oettingen’s texts are substantially larger than the others, thus likely leading to skewed results. Simply relying on relative frequencies or employing appropriate sampling techniques might resolve this issue.

5. Future steps

5.1. Annotation

In the next project phase, the transcribed texts will be annotated. In particular, we will add labels for *named entities* (e.g. persons, work titles) as well as a tag set specifically devised for

Table 3
Distributions of the 5 topics in all 9 texts of the corpus (in %). Topics accounting for more than 25% are highlighted.

ID	Topic 1	Topic 2	Topic 3	Topic 4	Topic 5
HAU1853	**48.36**	4.93	0.93	**41.65**	4.13
NAU1858	20.31	**60.12**	3.83	2.92	12.81
WEI1860	**47.76**	3.54	3.23	1.23	**44.25**
WEI1861	17.32	6.33	8.52	3.02	**64.81**
KUN1863	13.43	10.92	4.53	3.32	**67.80**
OET1866	11.83	17.71	**55.53**	3.62	11.32
THU1877	9.83	**52.24**	16.00	8.71	13.21
RIE1905	5.04	**58.53**	16.40	4.42	15.61
CAP1905	7.14	27.79	**50.24**	2.62	12.21

the genre of our texts. The labels thus obtained will constitute a minimal ontology tailored for our purpose, identifying concrete musical objects (e.g. 'interval', 'chord') as well as musical and scientific concepts, respectively. They will allow us to later analyze the music-theoretical vocabulary in more detail, and moreover permit to analyze conceptual networks between the texts and those terms in order to draw inferences about the discourse surrounding the debate on harmonic dualism. Due to the nature of our corpus, we expect that the first set of named-entity labels will be relatively small, whereas the second set of annotations will provide a valuable resource for digital musicology. However, close reading of the sources and initial annotations already suggest that the texts contain sufficient references to names of authors and composers and titles of works (texts or compositions) to be used for network analysis.

5.2. Music encoding

Our sources contain more than four hundred music examples, either specifically construed for demonstration or taken from a music piece as illustration. They were structurally marked up in the segmentation phase enabling automated extraction. Although *Optical Music Recognition* (OMR) has improved in recent years, it is still facing major challenges and currently lacks the reliability of state-of-the-art OCR frameworks [32, 3, 32, 34]. We plan to manually transcribe the examples to the **kern format, and convert them to the XML format of the *Music Encoding Initiative* (MEI) [9] as well as SVG using the engraving software *Verovio* [29]. Figure 4 (left) shows an example cadence taken from [4]. Other, more complex examples involve annotations or graphical elements, which renders symbolic music encoding difficult. We will thus only transcribe exclusively musical examples. We hope that the resulting pairs of scanned and rendered score examples may serve as a ground-truth data set to aid the further improvement of OMR.

5.3. Presentation

The scope of the project, a list of relevant sources, and the project team are presented on our GitHub page (https://dcmlab.github.io/ddd/). The corpus itself will be included on the website using *TEI Publisher*[7] that allows researchers to access the text and search for phrases.

[7]https://teipublisher.com/

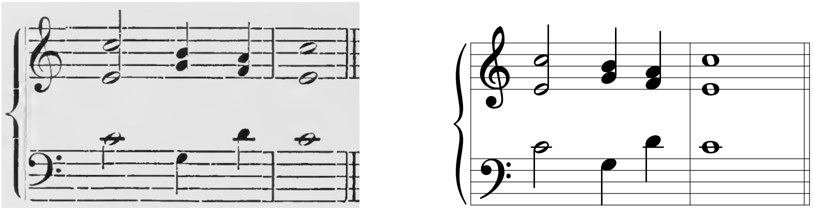


Figure 4: Score example from CAP1905 [4, p. 80, Fig. 4]. Left: Image extracted from Transkribus. Right: Modern rendering of **kern transcription with Verovio [29].

We are currently working on integrating the Verovio viewer into this framework in order to show the rendered scores (see Figure 4) instead of the scanned images, which will enable users also to play the musical examples. In future stages of the project, this website will also feature a summary of our main results and links to the relevant publications.

6. Conclusion

Drawing on a corpus of 19th-century German music theory texts, our project "Digitizing the Dualism Debate: a case study in the computational analysis of historical music theory sources" equally makes use of computational distant-reading and manual close-reading techniques [27], thus falling under a mixed-methods research paradigm [19]. By providing a machine-readable corpus of historical music theory texts and symbolic encodings of music, that enable computational analyses such as topic modeling, we hope that this project may serve as a proof of concept, upon which similar subsequent research projects in digital musicology and music theory can build.

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