THE INTERSECTION OF COMPUTATIONAL ANALYSIS AND MUSIC MANUSCRIPTS: A NEW MODEL FOR BACH SOURCE STUDIES OF THE 21ST CENTURY

Masahiro Niitsuma† **Tsutomu Fujinami**‡ **Yo Tomita**†
†School of Muisc and Sonic Arts, Queen's University, Belfast
‡School of Knowledge Science, Japan Advanced Institute of Science and Technology (JAIST)
niizuma@nak.ics.keio.ac.jp, fuji@jaist.ac.jp, y.tomita@qub.ac.uk

ABSTRACT

This paper addresses the intersection of computational analysis and musicological source studies. In musicology, scholars often find themselves in the situation where their methodologies are inadequate to achieve their goals. Their problems appear to be twofold: (1) the lack of scientific objectivity and (2) the over-reliance on new source discoveries. We propose three stages to resolve these problems, a preliminary result of which is shown. The successful outcome of this work will have a huge impact not only on musicology but also on a wide range of subjects.

1. INTRODUCTION

Recent developments in computer and information technology have brought significant changes to the ways in which we conduct research in a wide range of domains, and musicology is not an exception.

Yet in historical musicology the majority of scholars still conduct their research without making full use of this technological advancement, thus creating huge potential for future advancement.

By nature, their research methods are less scientific, i.e. they tend not to, or find it impossible to disclose all the information they used in order to arrive at their conclusions, and hence it is often difficult to verify their findings regardless of whether or not there are elements of subjective judgment in them.

There is a separate problem in musicology in that the majority of source-based studies heavily rely on the rediscovery of new sources.[1] Thus, if a new source is not found, there is often little discussion to challenge the existing interpretation offered by scholars in the past. Is there really no way of improving the theories unless a new source is discovered? How can a computer assist musicologists in analysing the information contained in the known sources?

The main objective of this study is to solve such problems in historical musicology by addressing the following questions:

1. Can computational analysis offer the same conclusions as those arrived at by historical musicologists?
2. Are there any oversights in the musicologists' analysis of the sources?

To achieve our objectives, it is necessary to address the following issues:

1. How to define a data structure for storing Bach's manuscripts in digital format;
2. How to extract information from the digitised manuscripts;
3. How to analyse the extracted information.

This paper is structured as follows: Section 2 describes the relationship between the proposed methods and existing scholarly debates in the field; Section 3 discusses the research methods to be employed; Section 4 shows a preliminary result of the proposed method; Section 5 illustrates the contribution that the proposed research will make; and Section 6 offers concluding remarks.

2. PREVIOUS RESEARCH

There are numerous research projects dealing with computation in musicology and different kinds of data formats have been proposed to encode musical data [1–3]. However, all of them deal with limited musical information such as pitch or rhythm derived from printed scores, and the majority of previous research on computational music analysis [4–9] is based on those data formats.

There is also a certain amount of research related to automatic music analysis using the signal-processing technique with acoustic sources [10–14], which record musical performance from published scores. But if we investigate only published scores, rather than the original manuscripts, we miss important information that has been lost in the process of creating an edition.

[1] Sources refer to manuscript sources, that is written scores by hand. Before the invention of printing, music was preserved either by oral transmission or by MS copies.

Recent journal articles or proceedings of ISMIR [15–17] includes a considerable number of researches on the Optical Music Recognition (OMR). Most of them deal with staff removal algorithm, which eases the preprocessing of the digitised images of the manuscripts such as the music symbol recognition.

With regard to the research related to manuscript analysis, Tomita developed a database of variants and errors which supposedly lists all the extant manuscripts and early prints of the Well-Tempered Clavier II, a work well known for its complex history of compilation, revision and transmission [18]. The database contains all kinds of information extracted from manuscripts – not only musical variants but also notational errors and variants that may have been inherited from its model or may cause errors when fresh copies were made from it – giving us many insights into how the future database should be developed.

3. METHODOLOGY

There are three stages in this project:

1. To define of a data structure for storing Bach's manuscripts in digital format;

2. To develop a methodology to automatically extract data from the digitised images of music manuscripts;

3. To develop a methodology to analyse these data to find significant information for musicological study.

In the first instance, a data structure that is appropriate to be analysed by computers needs to be defined. This data structure should be designed in such a way that it can encode all the information extracted from manuscripts – not only musical aspects such as pitch or rhythm, but also the physical aspects of the manuscript which may account for the scribe's unintentional omissions, misplacement, superfluous symbols that were somehow caused by the appearance of its exemplar. This has been investigated with the collaboration of musicologists.

Secondly, a method will be developed to harvest the information useful for research from the digitised images of the manuscripts. At the moment, we consider primarily the visible information such as the direction of stems or the position of note-heads. The first task is the recognition of each music symbol such as staff line, bar line, note stem, note head and clef. The Gamera [19] framework will be used for this task.

Finally, a method to analyse the data will be proposed. In order to achieve this, powerful machine learning methods such as bagging [20], boosting [21], and random forest [22] will be adopted.

Figure 1 illustrates how the proposed method operates. First, a digitised image file is created by physically scanning the manuscripts. Secondly, symbolic data is extracted from the digitised image file. Thirdly, computational analysis is carried out using the symbolic data.

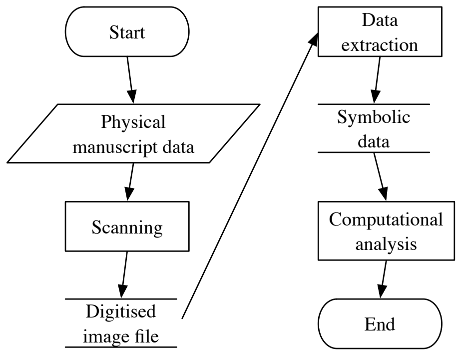

Figure 1. Flowchart of the proposed method

4. PRELIMINARY EXPERIMENT

4.1 An overview of the preliminary experiment

This sections presents a preliminary result of the third stage described under "3. Methodology". Currently, the first and second stages are conducted manually, while the program was developed for the third stage. To demonstrate the performance of the latter, the simplest example would be to examine the origin and authenticity of variants. Because WTC II was so popular among Bach's pupils and admirers during and after his lifetime, numerous manuscripts were made, copied and edited, which not only increased the number of errors or variant readings, but also resulted in introducing contamination to the texts in some sources [23, 24]. This program produces a source affiliation diagram showing how closely these sources were related, taking into account the differences that may be caused either by accident or on purpose while being copied.

In this paper, we focus on the sources of Viennese origin, which are considered to have been originated from a copy that was brought from Berlin to Vienna in 1777 by Gottfried van Sweieten (1734-1803). How the unique text of the Viennese sources evolved up has been the principal interest for musicologists, for this was the state of musical text which Mozart learned in 1782. In [25], Tomita investigated the Viennese sources, thereby proposing a source affiliation diagram of them, an excerpt of which is shown in Figure 2.

4.2 Preliminary result

We describe one approach to this task using the database developed by Tomita [24], an excerpt of which is shown in Figure 3, where S/N is the serial number given to each examination point; Bar indicates in which measure(s) the elements are examined; V, bt/pos stands for Voice, Beat and Position, respectively; Element specifies the target of enquiry; Spec. Loc gives graphic representation of information under examination; Classified suggests text-critical significance.

Firstly, the distance between two manuscripts should be defined. The simplest way is to count the number of different factors between two manuscripts.

In Figure 3, "Q11731" has no different factors from

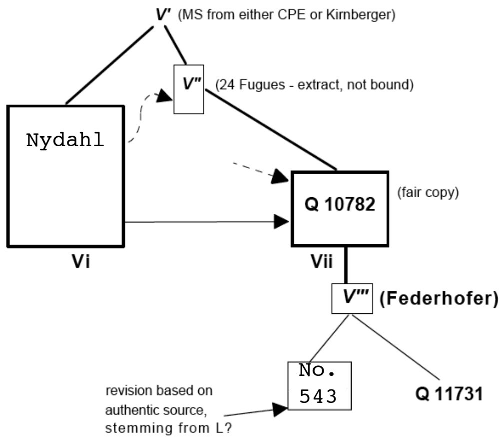

Figure 2. Score affiliation diagram of the Well-tempered Clavier Book II, generated by human analysis (excerpted from [18])

those of "No.543", thus the distance between "Q11731" and "No.543" is 0. On the other hand, "Q11731" has three factors which are different from those of "Nydahl", thus the distance between "Q11731" and "Nydahl" is 3. However, such observation dose not reflect the reality sufficiently. To improve the accuracy of observation, we should consider how easily each factor can change. For instance, notational factors such as the direction of the stem or position of the note-head are more likely to change than musical factors such as pitch or duration. Taking this into consideration, genealogical distance is defined by the following equation,

$$D(MSS1, MSS2) = \sum_{i=1}^{SN} \alpha_{Type_i} I(MSS1[i], MSS2[i]) \quad (1)$$

where, $MSS1$ and $MSS2$ denote two different manuscripts, $MSS[i]$ denotes the ith content of MSS, α_{Type_i} is the weight considering the fluidity of each type of the content, and $I(x, y)$ is the indicator function which returns 0 if $x = y$ else 1. In this paper, all α_{Type_i} were equalized, leaving an adjustment of α_{Type_i} as a future task.

50	51	52	S/N
14			Bar
S,1-	A,1/3	A,2	V,bt/pos
tie	acd	acd	Element
♩‿ [e♭'']	♪ [g']	♩ [a']	Spec.Loc
M-e	M-a, d	N-d	Classified
in	♯(♮) in	♯(♮) in	Nydahl
in	♮ in	♮ in	Q 10782
[illegible] ♩‿	♮ in	♮ in	No.543
[illegible] ×	♮ in	♮ in	Q 11731

Figure 3. Database used for the experiment (excerpted from [18]).

Secondly, manuscripts are clustered by a hierarchical cluster analysis using a set of dissimilarities calculated on the basis of Equation (1). Initially, each manuscript is assigned to its own cluster and then the algorithm proceeds iteratively, at each stage joining the two most similar clusters, continuing until there is just a single cluster. At each stage distances between clusters are recomputed by the Lance-Williams dissimilarity update formula according to the complete linkage method.

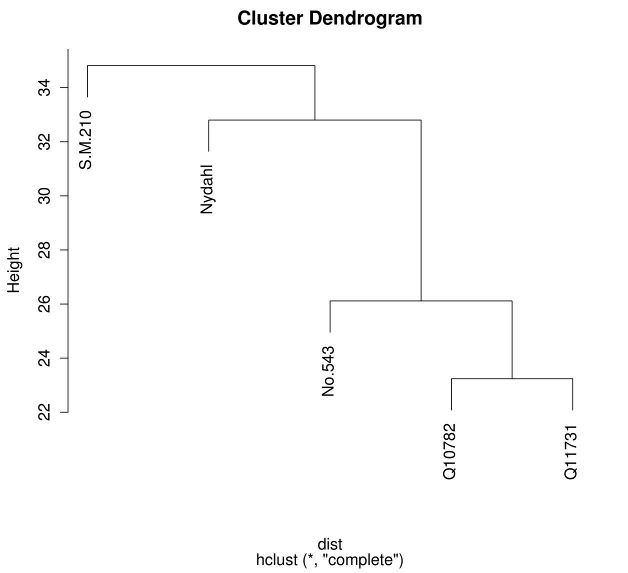

Figure 4. Score affiliation diagram of Fugue No.22 in B♭ minor from the Well-tempered Clavier Book II, generated by computational analysis

Figure 4 illustrates an example of source affiliation diagram automatically generated by the proposed algorithm. Manuscripts of Fugues 10, 12 and 14 were used to calculate the distance between each manuscript. This result is almost consistent with that of human analysis, while the position of No.543 (Berea) is considered to be different. This result indicates that this database is sufficient to achieve a rough classification; but to achieve a more reliable classification or for further analysis, it is necessary to develop a new data structure that is suitable for a more detailed computational analysis. The manual weighting of α_{Type_i} can reflect the expert knowledge of musicologists; however it could also reflect their own subjectivity. To exclude it, a method for automatic weighting of these factors should be investigated.

There are numerous possibilities of using these databases for analysis and the potential is far-reaching. Figure 5 shows biplot of the result of the principle component analysis. This reveals that there exists a large gap between Add.35021 (Bach's autograph manuscript) and the Viennese sources. Figure 6 shows the result of the variable importance estimation for the classification of the manuscripts of Fugue 23 by random forest, where y-axis corresponds to S/N of the text critical database. This indicates that S/N 475, and 136 are important for computer to classify them. These analyses using appropriate databases are considered

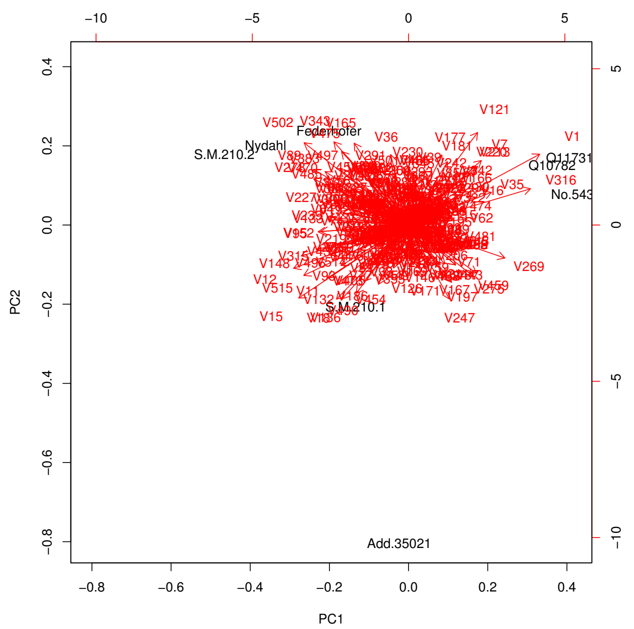

Figure 5. Biplot produced from the output of the principle component analysis of the text critical database of Fugue 23

to bring the objectivity and new findings to historical musicology.

Another area of investigation is an automatic handwriting analysis. The method for identifying handwriting in noisy document images [26] cannot directly be applied to music manuscripts. This is because handwriting identification needs not only visual information such as curvature (which represents the shape of the curves or bending angle) but also multifaceted information such as the purpose for which a manuscript was written, the scribe's habits, the conditions under which the manuscript was made, and so on. The proposed method is expected to overcome such difficulties by taking into account the multifaceted information with the appropriate database for computational analysis.

5. CONTRIBUTION

This research makes main contributions in the following areas:

1. The proposed method will provide a way to verify previous research in historical musicology;
2. It will be possible to offer new information about the sources from the already known sources;

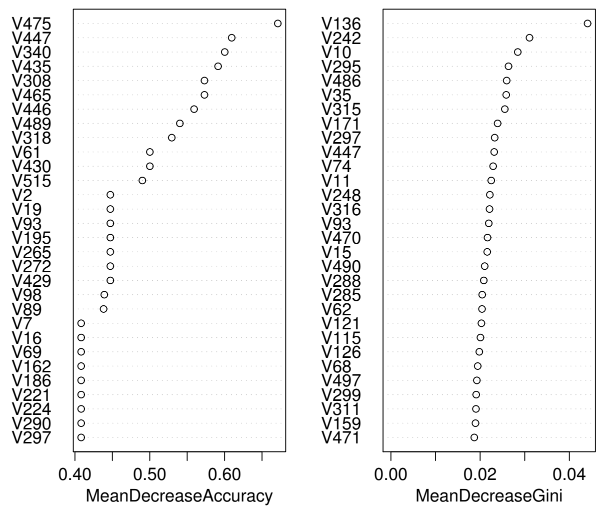

Figure 6. Result of variable importance estimation for the classification of Viennese sources by a random forest, where y-axis corresponds to S/N of Fugue 23 shown in [18]: for example, V475 is notation difference of rest in bar 89; V136 is the existence of accidental in bar32.

3. The proposed method can be a prototype of an empirical research method.

The result of the proposed research has a good potential for becoming a road map for musicological research of the future, and empirical research method would offer an alternative to the previous research methods often criticised for their inherent subjectivism. Consequently, it is hoped that the majority of previous research may be reworked by using the proposed methods. In this process, new discoveries can still be made that would shed new light on the musical works concerned without requiring the rediscovery of new sources. Moreover, the results of the proposed research may also serve as a prototype in other areas of research, such as archaeology, historical literature or other social science subjects that involve the study of historical sources.

6. CONCLUSION

In this paper, we have shown the necessity of using the computational approach in source studies. We also addressed the problems of subjective attitudes and its over-reliance on new source discoveries in traditional research methods in musicology. Three stages that may resolve these problems have been discussed. The outcome of this work should affect not only musicology but also a wide range of subjects.

7. REFERENCES

[1] Content-based unified interfaces and descriptors for audio/music databases available. http://www.cuidado.mu.

[2] Online music recognition and searching. http://www.elec.qmul.ac.uk/research/projects/ nsf_9905842_ omras.html.

[3] Web delivering of music. http://www.wedelmusic.org.

[4] Greg Aloupis, Thomas Fevens, Stefan Langerman, Tomomi Matsui, Antonio Mesa, Yurai Nuez, David Rappaport, Godfried, and Toussaint. Algorithms for computing geometric measures of melodic similarity. *Computer Music Journal*, 30(3):67–76, 2006.

[5] David Huron. Music information processing using the humdrum toolkit: Concepts, examples and lessons. *Computer Music Journal*, 26(2):11–26, 2002.

[6] Steven Jan. Meme hunting with the humdrum toolkit: Principles, problems and prospects. *Computer Music Journal*, 28(4):68–84, 2004.

[7] David Meredith. The ps13 pitch spelling algorithm. *Journal of New Music Research*, 35(2):121–159, 2006.

[8] Wai Man Szeto and Man Hon Wong. A graph-theoretical approach for pattern matching in post-tonal music analysis. *Journal of New Music Research*, 35(4):304–321, 2006.

[9] Heinrich Taube. Automatic tonal analysis: Toward the implementation of a music theory workbench. *Computer Music Journal*, 23(4):16–32, 1999.

[10] Lee Kyogu and Slaney Malcolm. Acoustic chord transcription and key extraction from audio using key-dependent hmms trained on synthesized audio. *IEEE Transactions on audio, speech, and language processing*, 16(2):291–301, 2008.

[11] Olivier Lartillot. A musical pattern discovery system founded on a modeling of listening strategies. *Computer Music Journal*, 28(3):56–67, 2004.

[12] Pierre Leveau, Emmanuel Vincent, and Gal Richard. Instrument-specic harmonic atoms for mid-level music representation. *IEEE Transactions on audio, speech, and language processing*, 16(1):116–128, 2008.

[13] Rui Pedro Paiva, Teresa Mendes, and Amlcar Cardoso. Melody detection in polyphonic musical signals: Exploiting perceptual rules, note salience, and melodic smoothness. *Computer Music Journal*, 30(4):80–89, 2006.

[14] Li Yipeng and Wang DeLiang. Musical sound separation using pitch-based labeling and binary time-frequency masking. *Proceedings of International Conference on Acoustics Speech and Signal Processing*, pages 173–176, 2008.

[15] C. Dalitz, B. Czerwinski M. Droettboom, and I. Fujinaga. A comparative study of staff removal algorithms. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 30(5):753–66, 2008.

[16] J. Hockman Pugin, L., J.A. Burgoyne, and I. Fujinaga. Gamera versus aruspix: Two optical music recognition approaches. *Proceedings of the International Conference on Music Information Retrieval*, pages 419–424, 2008.

[17] John Ashley Burgoyne, Johanna Devaney, Laurent Pugin, and Ichiro Fujinag. Enhanced bleedthrough correction for early music documents with recto-verso registration. *Proceedings of the International Conference on Music Information Retrieval*, pages 407–412, 2008.

[18] Yo Tomita. *J. S. Bach's 'Das Wohltemperierte Clavier II' A Critical Commentary. Volume II: All the Extant Manuscripts*. Leeds: Household World, 1995.

[19] The Gamera framework for building custom recognition systems. Michael droettboom and karl macmillan and ichiro fujinaga. *Proceedings of the Symposium on Document Image Understanding Technologies*, pages 275–86, 2003.

[20] L Breiman. Bagging predictors. *Machine Learning*, 24(2):123–140, 1996.

[21] Y Freud and R.E Schapire. Experiments with a new boosting algorithm. *Proceedings of the Thirteenth International Conference on Machine Learning*, pages 148–156, 1996.

[22] L Breiman. Random forests. *Machine Learning*, 45(1):5–32, 2001.

[23] Yo Tomita. Breaking the limits: some consideration on an e-science approach to source studies. *Musicology and Globalization. Proceedings of the international Congress of the Musicological Society of Japan*, pages 233–237, 2002.

[24] Yo Tomita and Tsutomu Fujinami. Managing a large text-critical database of Johann Sebastian Bach's Well-Tempered Clavier II with XML and relational database. *Proceedings of the International Musicological Conference*, 2002.

[25] Yo Tomita. The Sources of J.S. Bach's Well-Tempered Clavier II in Vienna, 1777-1801. *BACH: Journal of the Riemenschneider Bach Institute*, 29(2):8–79, 1998.

[26] Yefeng Zheng, Huiping Li, and David Doermann. Machine printed text and handwriting identification in noisy document images. *Pattern Analysis and Machine Intelligence*, 26(3):337–353, 2004.