

7 Assessing Disputed Attributions for Organ Fugues in the J. S. Bach (BWV) Catalogue

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Abstract

We describe a computational approach to musical authorship problems in which machine-learning algorithms are used to recognize personal musical styles. The algorithms learn characteristics from representative examples and are able to use the obtained knowledge to classify previously unseen compositions. The pilot project focuses on several organ fugues in the catalog of J. S. Bach (BWV 534/2, 536/2, 537/2, 555/2, 557/2, 560/2 and 565/2) the attributions of which have been challenged in recent years. With a nearest-neighbor classifier, these disputed fugues have been compared to a number of fugues indisputably by J. S. Bach as well as the contenders J. L. Krebs, J. P. Kellner and W. F. Bach. This comparison has been done in a subspace spanned by a selected optimal set of features. It appears that this comparison provides valuable contributions to discussions about the authorship of these pieces. Some hypotheses from musicological literature can be either confirmed or rejected.

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7.1 Bases for Composer Attributions

One task of musicology is to study the musical past. A common approach has been to provide an overview of the most important composers of each era together with their compositions, then to study the relationships of these compositions to each other and to musical and non-musical contexts. A complementary activity has been the preparation of critical editions of scores. In these activities the question of authorship remains paramount. If we want to present the most important composers and their works, we need to know who composed what. If we want to make a critical edition of the works of a certain composer, we cannot escape making decisions about disputed compositions. Problems may be caused by conflicting attributions among plural sources, the lack of an authoritative source contemporary with the composer, an incomplete source, or an anonymous source which tradition holds to be by the composer. Attributions of the same work to multiple composers is a common phenomenon of European works of the fifteenth through nineteenth centuries.

Both external and internal evidence may be used to solve authorship problems. A letter from a composer in which he mentions a recent composition provides strong support to claim his authorship in the presence of a rival claim. In many cases, however, external evidence of a decisive nature is lacking. Here, internal evidence becomes more important. Internal evidence may focus on handwriting, text underlay (in vocal music), physical features of the paper (e.g., watermarks, raster-line spacing), and other philological considerations. Countless disputes about the authorship of musical works stem from diverse norms of judgment about discrepancies between internal and external evidence. Stylistic evidence, which is explored here, is unlikely to sway the opinion of someone who rejects an otherwise documented work which lacks a copy signed by the composer. However, it can bring additional perspective to discussions of works whose authorship is truly unresolved.

In order to assess stylistic evidence one must have a model that is able to represent musical styles in such a way that specific instances of it can be associated with a composer's personal style to a unique degree. In manual practice, proof by example is often used to support an attribution on stylistic grounds. The most pertinent feature may be a distinctive motif or chord progression that is present both in the disputed work and in an undisputed composition. Such similarities might, however, be occasional. If we want to support an attribution in a statistically sound way, we have to use events which occur frequently (such as notes and intervals).

Computer-based assessment of musical authorship was first extensively explored by Trowbridge (1982; 1985-6), who revealed differences in style among four Renaissance composers (Gilles Binchois, Antoine Busnois, Guillaume Dufay, and Johannes Ockeghem) by comparing the average values of 16 quantifiable features (Trowbridge 1985-6). The repertory evaluated consisted of 92 Renaissance chansons, of which two-thirds exist in a single manuscript copy with scribal attribution. Many of the rest are anonymous in at least one source, a few in more than one source. Many of the fea-

tures are coincidentally similar to those used here. They included melodic intervals, harmonic intervals, chord types, bass progressions, root progressions, root distributions, prepared dissonances, chord durations, chord motion, texture reduction, melodic direction, rhythmic activity, average melodic range, relative melodic motion, voice crossing, and harmonic range. A good account of still earlier systems for quantitative analysis is given in Trowbridge (1982). For polyphonic music Trowbridge's thesis is by far the most thorough and comprehensive of its time.

Far more prevalent today are studies that isolate and analyze musical features for differentiation of pieces by genre (e.g., McKay and Fujinaga 2004), mood (e.g., Dannenberg 1997), or idiosyncratic traits of individual composers (e.g., Cope 1991, Cope 1998). Cope's intent was to replicate style and genre of individual composers in his very extensive Experiments in Musical Intelligence (1980-2005).

7.2 A Machine-Learning Approach to Stylistic Assessment

Our approach to authorship problems employs machine-learning algorithms. These algorithms learn characteristics of musical styles from representative examples, and are then able to use the obtained knowledge to classify previously unseen compositions. The repertory on which we focus here consists of seven organ works attributed in the Schmieder (BWV) catalogue (1950/2nd rev. edn. 1990) to Johann Sebastian Bach but disputed on stylistic (or other) grounds in recent musicological literature. In an earlier publication the authorship of the fugue for organ in F minor (BWV 534/2) was evaluated (Backer and Van Kranenburg 2005). In the current article, another classification algorithm is used and the dataset extended with six additional fugues listed in Schmieder and with control compositions by Johann Peter Kellner. The works investigated experimentally here and the proponents for and against Bach's authorship are summarized in Table 7.1.

BWV number, title*	Supporting J. S. Bach's authorship	Questioning J. S. Bach's authorship	Proposed alternative composer or medium
BWV 534/2		Humphreys (1985)	Kellner or J. L. Krebs
	Breig (1993), with reservations about dating		
		Dirksen (2000)	W. Fr. Bach
BWV 536/2		Humphreys (1989, 2000)	Attributed to Kellner
BWV 537/2		O'Donnell (1989)	Fugue ending by Joh. Ludwig Krebs
	Breig (2000)		

BWV number, title*	Supporting J. S. Bach's authorship	Questioning J. S. Bach's authorship	Proposed alternative composer or medium
BWV 555/2		Keller (1937)	Possibly by Krebs
		Tittel (1966)	Not by Krebs
BWV 557/2		Keller (1937)	Possibly by Krebs
		Tittel (1966)	Not by Krebs
BWV 560/2		Durr (1987)	
BWV 565/2		Williams (1981)	Transposed from solo violin work in A Minor?
		Humphreys (1982)	Attributed to Kellner
	Claus (1998), but suggests late rather than early work. Rejects possibility of Kellner's authorship.		
		Billeter (2004)	For cembalo?

Table 7.1. Summary of recent claims about the authorship of particular Bach organ fugues. [The indication (*2 signifies the second movement (i.e. the fugue) of a prelude-fugue pair.]

(Questions of performing medium—violin vs. keyboard, harpsichord vs. organ—have not been investigated here, since they would require evaluation of different features from those used to evaluate authorship and a different set of control works.)

7.3 Modeling Musical Style

In *Style and Music* Leonard Meyer developed a theory of musical style that can be used as a starting point for studies that compare musical styles algorithmically. He defines style as a replication of patterning, whether in human behavior or in the artifacts produced by human behavior, that results from a series of choices made within some set of constraints (Meyer 1996: 3). In the process of composing, a composer is subjected to certain constraints while making his choices. Meyer distinguishes three levels of constraints. *Laws* (1) are universal. One cannot, for example, ask a piccolo to play a contra G. *Rules* (2) are intracultural. It is in the rules that music from the Renaissance differs from music from the Baroque. *Strategies* (3) are constraints to which the composer subjects himself within the rules of a certain culturally established style. Thus it is in the strategies that the music of G. F. Handel differs from the music of G. Ph. Telemann.

Not all strategies reside on a conscious level. Certain patterns are ingrained during the training and development of a composer and are not replicated consciously every time during the process of composing. (Meyer's "unconscious strategies" correspond

to the concepts of unconscious “fingerprints,” “signatures,” and “earmarks” in the extensive work on style simulation by David Cope (1991, 1998 et al.).

Meyer indicates the necessity of statistics: since all classification and all generalization about stylistic traits are based on some estimate of relative frequency, statistics are inescapable (Meyer 1996: 64). It can be expected that each composer has idiomatic, countable patterns that are more often replicated in his works than in compositions by other composers. The task is to find features in which such patterns are reflected.

7.4 The Dataset

7.4.1 Selected Features

There is no well-tested theory available that predicts which features have to be used to solve a particular authorship problem. Therefore, we do an “educated guess” at features that may have discriminative power. The subset of features that can be used to solve the authorship problem in question will be selected algorithmically.

Small-scale features are preferable, because the algorithms to extract them are less complicated and the results less ambiguous. It is, for example, not obvious how to quantify the extent to which a composition resembles a certain sonata form, but it is less difficult to count the number of thirds. Because in the current study we are dealing with polyphonic music (fugues), the relations between the voices are important. The composer must know, for example, whether a dissonant interval can be written between two voices, how long that interval is allowed to sound, and what can follow. It can be expected that a composer develops certain strategies to handle these situations. This can result in replicated patterns in the distances between the voices and many other conventions of part-writing.

The following 20 features are chosen:

Features 1–9: Intervals weighed by duration. The total duration of all occurrences of each specific interval is computed and at the end divided by the total duration of all intervals in all voice pairs. The intervals are folded onto one octave (e.g., a tenth is counted as a third). If the same pitch occurs in more than one voice, it is taken into account only once.

1. Seconds
2. Thirds
3. Perfect fourths
4. Augmented fourths
5. Diminished fifths
6. Perfect fifths
7. Sixths between parts
8. Sevenths between parts

9. Octaves between parts

Features 10–12: Parallel motion. The quantity of parallel thirds, fourths, and sixths is computed in the same way as for Features 1–9. The total duration of all intervals involved in these parallels is computed and divided by the total duration of all intervals in all voice pairs.

10. Parallel thirds

11. Parallel fourths

12. Parallel sixths

Features 13–16: Dissonance treatment. Perfect primes, minor and major thirds, perfect fourths, perfect fifths, and minor and major sixths are considered consonant. A fourth is considered dissonant if it is between the lowest voice and one of the upper voices. All other intervals are considered dissonant. The total duration of dissonant sonorities is divided by the total duration of the composition.

13. Suspension resolved stepwise in lower voice.

14. Voice density (average number of voices active in composition). Normalized for the total number of voices. Only bars that are strictly polyphonic are taken into account.

15. Dissonance between parts. The fraction of the score in which the sonorities are dissonant.

16. Bars beginning with dissonance. The percentage of bars that begin with a dissonant sonority.

Features 17–19: Entropy measures. Computed according to Shannon's formula (1948).

17. Harmonic entropy (array of chord-types used). A measure of chord quality (e.g., the F-major and G-major triads are considered to be the same sonority). Inversions are not taken into account.

18. Pitch entropy (array of pitches used). A list of occurrences of all pitches is made. Again the occurrences are weighted by the durations.

19. Sonority entropy (array of features used). A sonority is a certain type of chord (e.g., all major triads are the same sonority, regardless of inversion, pitch, or doubling of tones). Each sonority has a unique number. For each sonority the total duration of all occurrences in the composition is computed. Then the probabilities of occurrence are estimated using this weighted frequency.

Feature 20. Time-slice stability. The consistency of the length of successive time-slices (e.g., the time interval between two changes in the music). Stability is computed by dividing the standard deviation of the lengths of the time-slices by their mean length. This normalization is necessary in order to compare pieces with different time signatures. So, when having a low value, the music is more like a steady stream, while a larger value indicates more diversity in rhythm. Bars which are not fully polyphonic (i.e., those containing a cadenza or arpeggiated chords) are ignored in computation.

7.4.2 The Control Compositions

Four composers are represented in the control dataset: J. S. Bach (1685-1750), his son Wilhelm Friedemann Bach (1710-84), his student Johann Ludwig Krebs (1713-80), and Johann Peter Kellner (1705-1772), who was a great admirer of J. S. Bach and played an important role in the copying and transition of Bach's organ compositions. Not many other composers among the students and contemporaries of J. S. Bach might have composed fugues comparable to those of J. S. Bach. However, an assignment of a disputed fugue to one of these four composers does not lead automatically to an attribution. The possibility that a composer not represented in the dataset wrote the piece should be kept open. In general, it is desirable to have external evidence that points exclusively at only a few candidates before pursuing the stylistic approach in the hope of making a definitive attribution.

Because of the time-consuming process of data entry, not all fugues by J. S. Bach and J. L. Krebs were encoded. To lower the probability of incorporating misattributions somewhat, only the fugues of Kellner that appeared in print are incorporated. In the case of W. F. Bach, the included five fugues are the only ones suitable for our purpose. In all, 35 works of undisputed authorship were encoded. See Table 7.2.

Composer (No. of works)	Compositions
J. S. Bach (9)	BWV 535a/2, 535/2, 538/2, 540/2, 541/2, 542/2, 543/2, 545/2, 547/2
J. L. Krebs (8)	Fugue in C minor (I, 2), E major (I, 5), F minor (I, 6), G major (I, 8), F major (II, 13), F minor (II, 14), F minor (II, 15), B flat major (II, 19)
W. F. Bach (5)	Faulk 33, 36, 37, Add. 211/1, Add. 211/2
J. P. Kellner (6)	O08:01, O08:06, O08:07, O08:[C], O08:[F], O10:02
Disputed fugues (7)	BWV 534/2, 536/2, 537/2, 555/2, 557/2-560/2, 565/2

Table 7.2. *The incorporated organ fugues. The J. S. Bach numbering follows Schmieder (1990); that for Krebs, the edition of organ music by Weinberger (Krebs 1985); for W. F. Bach, the catalogue of Falck (1956), with additions by Peter Wollny (1993); for Kellner, the catalogue by Claus (1999). Two fugues by Kellner not yet listed in Claus's catalog start with the designation "O08." In order to give them separate identities, I have added the key in square brackets.*

All of the works evaluated in this study were encoded in the Humdrum kern format and will be made available at <http://kern.ccarh.org>.

7.5 Data-Analysis Methods

To increase the amount of data available for control purposes, each composition was cut into overlapping segments of 30 bars, such that Segment 1 = Bars 1–30, Segment 2 = Bars 2–31, etc. (see Figure 7.1 for a generalized view). To produce reliable values, the minimum length of a segment has to be around 30 bars (Backer and Van Kranenburg 2005).¹ Since there is a large degree of redundancy from one segment to the next, however, the window measurements are not independent. This must be accounted for when applying machine-learning algorithms.

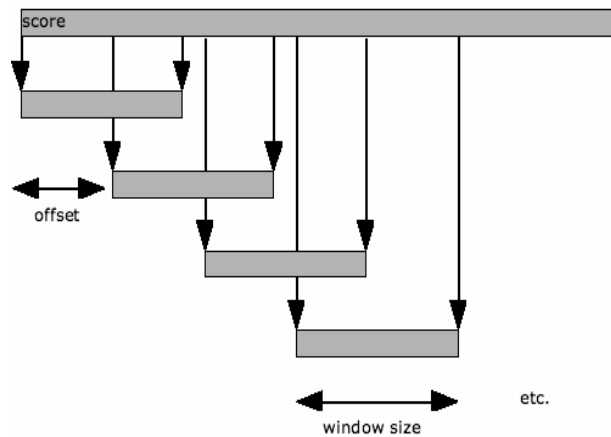


Figure 7.1. Schematic view of overlapping segments used in the analysis.

After measuring the 20 features in all segments, the data is represented by a cloud of points in a 20-dimensional space (the feature space). To make the scales of the features comparable, the dataset is normalized. For each feature, the mean is shifted to zero and the values are divided by the standard deviation.

Some features may be better suited to classification than others. Choosing the “wrong” features may lead to more confusion. Therefore, Pudil’s floating forward feature-selection algorithm (1994) has been applied. This algorithm successively adds or removes one or more features in order to optimize a certain criterion.

In order to get an indication of the reliability of a classification algorithm, the error rate is estimated as follows: each composition is successively removed from the dataset, a classifier is trained on all other compositions, and the data points of the removed composition are classified. Then the error rate of all compositions is averaged. In this way the dependency of the data points is accounted for. For convenience, I will call this error rate the leave-one-composition-out error rate (LOCO error rate).

Because we are interested in the catalog of J. S. Bach, the styles are evaluated in pairs, each consisting of J. S. Bach and one of the other composers. For each pair the optimal subset of features is selected using the Pudil algorithm. The criterion that is op-

timized is the LOCO error rate of a nearest-neighbor classifier. A nearest-neighbor classifier assigns the unknown object to the labeled object that is nearest in the feature space. The advantage of this classifier in the current situation is that no assumption is made about the distribution of the data points. Only local densities are used. In Table 8.3, for each pair of composers, the selected features are shown, together with the corresponding LOCO error rates for the compositions of J. S. Bach and for the compositions of the other composer.

7.6 General Findings

In the case of J. L. Krebs, the selected optimal subset consists of 12 features with an overall error rate of 1.5%, but for subsets with more than five features, the error rate decreases only marginally. (The specific features used in each comparison are indicated in Table 7.3. To give an impression of the data comparisons, scatter-plots in Figures 7.1a, b, and c show two musical features for each comparison.)

Classes	Selected features	Error / J. S. Bach	Error / other
J. S. Bach vs. J. L. Krebs	1, 2, 8, 15, 16	4.5%	2.1%
J. S. Bach vs. J. P. Kellner	9, 13, 20	0%	3.2%
J. S. Bach vs. W. Fr. Bach	3, 5, 8, 11, 15, 16, 18, 20	1.6%	19.3%

Table 7.3. The chosen feature subset for each of the two-class problems with corresponding LOCO (leave one composition out) error rates.

7.6.1 J. S. Bach vs. J. L. Krebs

One important difference between J. S. Bach and J. L. Krebs is that Bach used more seconds and sevenths and fewer thirds than Krebs. In general, J. S. Bach's pieces contain more dissonances. The only composition that causes trouble with the set of five features selected for the comparison is the Fugue in G Minor BWV 542/2. Twenty-four of the 80 segments are misclassified. With the optimal set of 12 features, only one segment is misclassified. Therefore it is better to take the set with five features, and accept the partial misclassification of BWV 542/2.

7.6.2 J. S. Bach vs. J. P. Kellner

For recognizing the styles of J. S. Bach and J. P. Kellner, three features proved to be sufficient. The J. S. Bach segments have more dissonances revolved by step. They also have a steadier rhythm than the Kellner segments. Kellner's O08:06 and O08:[F] utilize more octaves than the pieces by J. S. Bach.

7.6.3 J. S. Bach vs W. Fr. Bach

Eight features are needed for optimal classification. It appears that the error is mainly caused by misclassification of Faulk 33 (16 out of 51 segments) and Faulk add. 211/2 (27 out of 51 segments). The combination of the selected features is too complex to allow one to characterize the differences between J. S. and W. F. Bach in a few sentences. Style discrimination for this pair is more difficult than for the other two.

To give an impression of the data in each comparison, scatter-plots are shown in Figures 7.2a–c for the two most significant features in each individual pair of composers. These sets are the optimal sets of size two found by the Pudil algorithm.

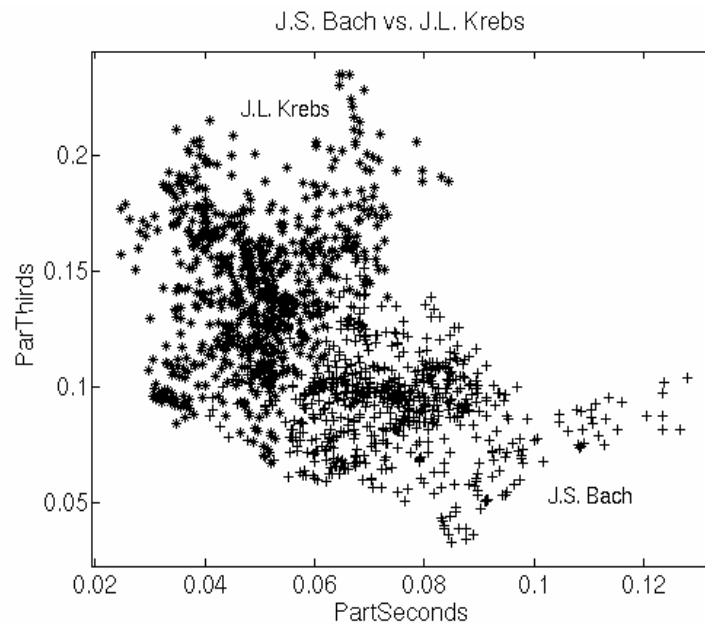


Figure 7.2(a). Projection of the segments onto the planes spanned by the two most important features for J. S. Bach compared to J. L. Krebs.

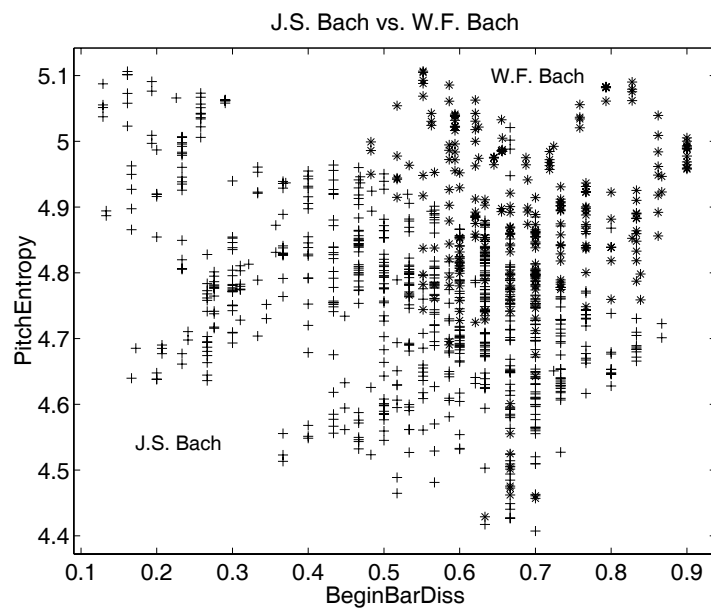
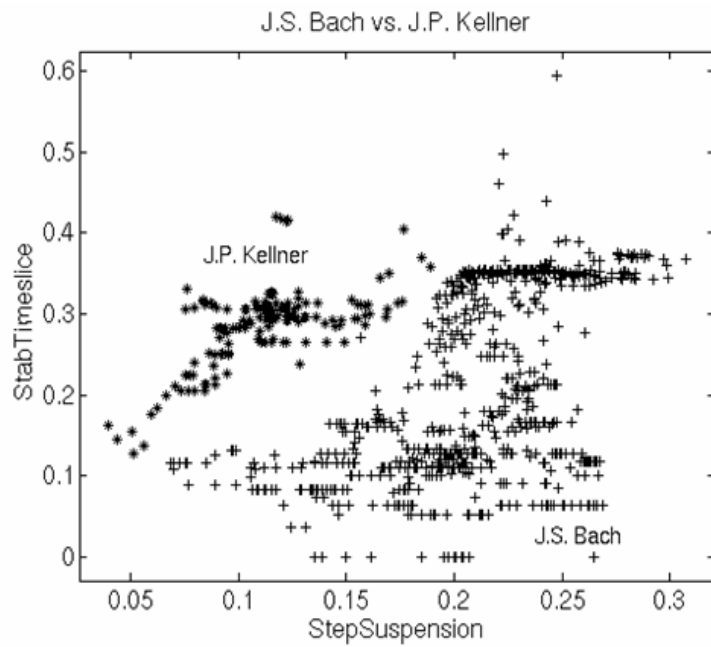


Figure 7.2, cont. Projection of the segments onto the planes spanned by the two most important features for (b, upper figure) J. S. Bach compared to J. P. Kellner, and (c, lower figure) J. S. Bach compared to W. Fr. Bach.

7.7 Classification of the Disputed Works

The classification results for the disputed fugues are shown in Table 7.4. The compositions will now be discussed individually, since the sets of parameters which proved to be most significant varied from work to work.

BWV No. of work	J. S. Bach compared to	Proportion of segments classified as J. S. Bach	BWV No. of work	J. S. Bach compared to	No. of segments classified as J. S. Bach
534/2	J. L. Krebs	34 / 102	555/2	J. L. Krebs	5 / 84
	Kellner	54 / 102	557/2	Kellner	61 / 84
	W. F. Bach	94 / 102	560/2	W. F. Bach	84 / 84
536/2	J. L. Krebs	94 / 135	565/2	J. L. Krebs	24 / 50
	Kellner	134 / 135		Kellner	46 / 50
	W. F. Bach	135 / 135		W. F. Bach	50 / 50
537/2	J. L. Krebs	74 / 95			
	Kellner	95 / 95			
	W. F. Bach	75 / 95			

Table 7.4. Classification results for the disputed fugues. For each fugue the number of segments that are classified as J. S. Bach is shown as a fraction of the total number of segments in the piece.

7.7.1 BWV 534/2

Although early writers on the organ works of Bach like Philipp Spitta, Albert Schweitzer and Hermann Keller did not esteem the Fugue in F Minor, BWV 534/2, as much as other fugues, the authorship was not doubted (Spitta 1916: 583, Schweitzer 1955: 238, Keller s.a.: 79f). In 1985 David Humphreys rejected this fugue as a composition by J. S. Bach. Dirksen (2000) suggested W. F. Bach as the actual composer. From Table 7.4 it is clear that the attribution to W.F. Bach is not supported. It is more difficult to adjudicate between J. S. Bach and Kellner. Classification between J. S. Bach and J. L. Krebs points strongly in the direction of Krebs, but the attribution to Krebs is not really convincing. If Krebs had composed the piece, the part of it that is misattributed (33%) is larger than for all involved undisputed fugues by Krebs. This fugue might have been composed by another composer.

7.7.2 BWV 536/2

The fugue in A major, BWV 536/2, has been rejected as a composition of J. S. Bach by David Humphreys (Humphreys 1989). In the earliest source, J. P. Kellner is the writer of the prelude, but the fugue is in a later, anonymous hand. Humphreys suggested J. P. Kellner or one of his pupils as the composer. The result of the J. S. Bach vs. J. P. Kellner classifier does not support the authorship of Kellner. Almost all segments are assigned to the class of J. S. Bach. The trajectory of this fugue in the plane that is spanned by the most important features (regularity in rhythm and stepwise resolved dissonances) is shown in Figure 7.3. After the exposition, the rhythm becomes more regular than in most other pieces by J. S. Bach (a value of zero for Feature 20 means that there is no variation at all in the combined rhythm of all voices). Therefore we can conclude that Kellner is in all probability not the composer of this piece, but it is also not a typical J. S. Bach fugue.

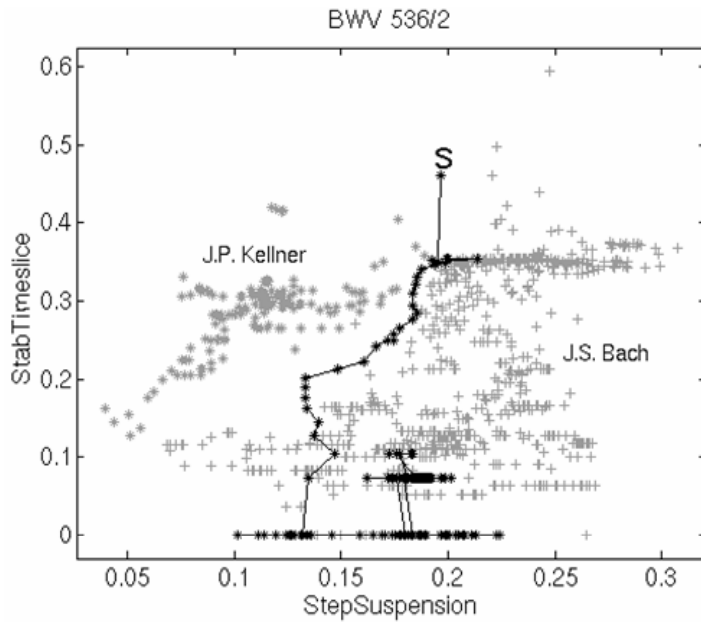


Figure 7.3. Projection of the trajectory of BWV 536/2 onto planes spanned by the two most important features for the pair of composers. The first segment of the fugue is marked by “S”.

7.7.3 BWV 537/2

A very interesting hypothesis about the fugue in C minor (BWV 537/2) was posed by John O’Donnell (1989). In the earliest source the first 90 bars are written down by Johann Tobias Krebs (1690-1762) and the remaining 40 bars by his son, Johann Ludwig. This is one of the reasons for O’Donnell to suppose that the piece was left unfinished by J. S. Bach and was completed by J. L. Krebs on request of his father, who was copying the score. The classifier assigns the last 13 segments to J. L. Krebs. These correspond almost exactly with the last 40 bars. The trajectory of the piece in the plane spanned by the two most important features (seconds and parallel thirds) is interest-

ing (Figure 7.2a). The trajectory starts in the cluster of J. S. Bach. From bar 60, a second, chromatic theme dominates the fugue. As soon as the segments contain bar 60 or higher, the trajectory goes into the cluster of Krebs, but with a relatively large number of seconds. The following part, in which the chromatic theme dominates all segments entirely, goes outside both clusters. Finally, the trajectory ends in the heart of the cluster of Krebs. A chromatic theme is rare in J. S. Bach’s organ fugues. This might explain why the trajectory goes outside the J. S. Bach cluster early. Bach probably changed his strategies by writing more thirds, but Krebs was able to use his “normal” amount of seconds and parallel thirds while composing the last 40 bars. So they treated the chromatic theme in a different way. In any case, the current results support the claim that this fugue was composed by two composers. The authorship of J. L. Krebs for the last 40 bars is likely. See Figure 7.4.

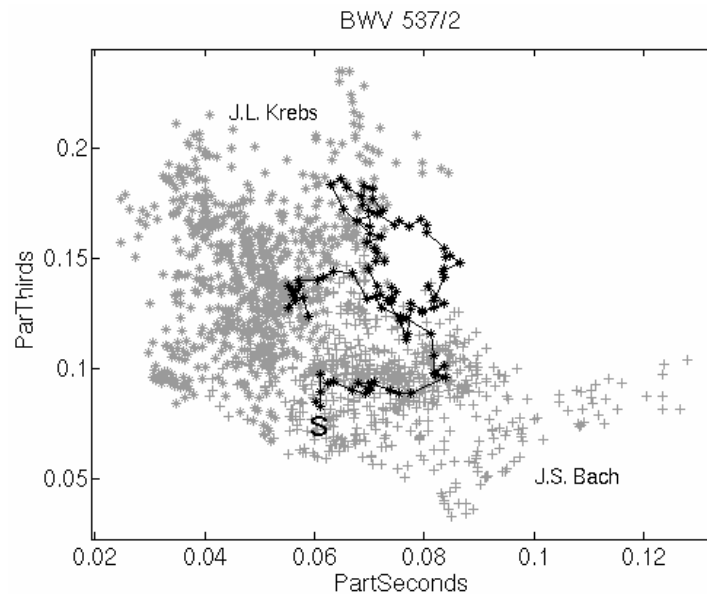


Figure 7.4. Projection of the trajectory of BWV 537/2 onto planes spanned by the two most important features for the pair of composers. The first segment of the composition is indicated by “S”.

7.7.4 BWV 555/2, 557/2, 560/2

These five fugues are part of the *Acht kleine Präludien und Fugen*. The other three fugues of this collection are too short to measure reliable feature values (less than 30 bars). The authorship of these eight little preludes and fugues has been much discussed. The relatively low quality has been an important reason for this. Several composers are suggested, among them J. L. Krebs (Keller 1937: 67f). But there is also a rejection of the authorship of Krebs (Tittel 1966). The classification results in Table 7.4 support the rejection of the authorship of J. S. Bach. W.Fr. Bach can also be excluded. It can be concluded that, out of the set of composers included in this study,

these fugues share most the characteristics of the style of Krebs. But again, it might very well be that they were written by another composer whose style is not represented in the dataset.

7.7.5 BWV 565/2

The case of the fugue in D minor BWV 565/2 is interesting because it is part of the most famous organ work in existence, the Toccata in D minor. Although this piece is known to almost everyone in western society as *the* organ piece by J. S. Bach (especially the beginning), its authorship is disputed, mainly because the style of the work differs so much from all other organ works by J. S. Bach. Several theories have been posed, but it is still an unresolved question. Because the earliest source was written down by J. P. Kellner's student Johannes Ringk, Kellner might be considered a candidate. In an extensive study, Rolf Dietrich Claus concludes that Bach cannot be the composer. Neither is an attribution to Kellner made (Claus 1998). This is in accordance with the current results. The classification of half the piece as J. L. Krebs supports questioning the authorship of J. S. Bach, and in comparison with the style of Kellner, BWV 565 more resembles the style of J. S. Bach. The trajectory is shown in Figure 7.5. Apart from the first segment, the style is rather consistent under this projection. Although the proportion of dissonances that is stepwise resolved is in accordance with some pieces by Kellner, the regularity of the combined rhythm of all voices is clearly not.

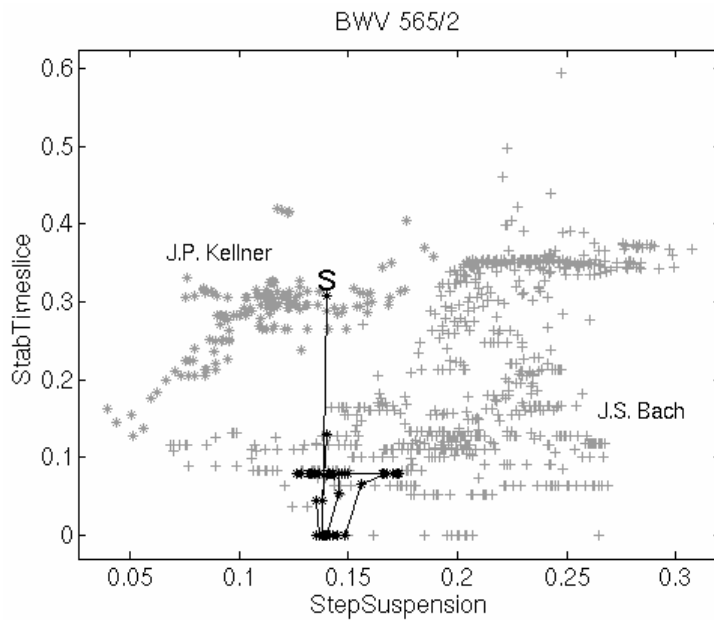


Figure 7.5. Projection of the trajectory of BWV 565/2 onto planes spanned by the two most important features for the pair of composers. The first segment of the composition is indicated by "S".

7.8 Conclusions

By way of a summary, we provide as Table 7.5 a revised version of Table 7.1. (Questions concerning medium of performance have not been evaluated in this study and are therefore not cited in Table 7.5.)

BWV Number, Title	Referenced literature	Implications of statistics
BWV 534/2	Humphreys (1985)	Kellner or J. L. Krebs? No clear answer.
	Dirksen (2000)	Not by W. Fr. Bach.
BWV 536/2	Humphreys (1989, 2000)	Attributed to Joh. Peter Kellner. Not by Kellner, but profile not typical of J. S. Bach.
BWV 537/2	O'Donnell (1989)	Last 13 bars by J. L. Krebs (confirming O'Donnell).
BWV 555/2	Keller (1937)	Not by W. F. Bach; could be by Krebs or composer outside dataset.
BWV 557/2	Tittel (1966)	
BWV 560/2	Dürr (1987)	
BWV 565/2	Humphreys (1982)	Not by Kellner

Table 7.5. Results of computer evaluation of attribution issues related to musical style.

In sum, it can be seen that although this study cannot always establish the author, it can confirm some hypotheses about alternative authors and refute others. For several works, authorship remains an open question, since the possibility exists that the true author was not included in the dataset.

It is shown that the proposed quantitative approach to the recognition of personal styles of composers results in valuable additions to existing authorship disputes (in this case about some of the disputed organ fugues in Bach's catalog). Although the current results do not offer enough evidence to draw final conclusions for these compositions, it is clear that this method is helpful in finding and testing hypotheses about differences in personal styles. Because the available data (scores) are extensively used, these hypotheses are firmly connected to the scores. This is unlike many "traditional" studies, in which proof by example is the best achievable.

In order to interpret results from methods like these, statistical studies should be accompanied with musicological theories about musical style. A possible theory has been offered by Meyer (1996). This should be extended with a theory that predicts which patterns (features) will be important for a specific problem. For compositions that are not strictly polyphonic, a set of relevant features still needs to be identified.

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Notes

1. In the control database Kellner's O08:[C] consists of only 25 bars and therefore had to be analyzed in shorter segments.

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