PITCH CLASS SET CATEGORIES AS ANALYSIS TOOLS FOR DEGREES OF TONALITY

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ABSTRACT

This is an explorative paper in which we present a new method for music analysis based on pitch class set categories. It has been shown before that pitch class sets can be divided into six different categories. Each category inherits a typical character which can "tell" something about the music in which it appears. In this paper we explore the possibilities of using pitch class set categories for 1) classification in major/minor mode, 2) classification in tonal/atonal music, 3) determination of a degree of tonality, and 4) determination of a composer's period.

1. INTRODUCTION

In Western classical music a distinction can be made between tonal and atonal music. Tonal music is based on a diatonic scale which inherits hierarchical pitch relationships. The pitch relationships are based on a key center or tonic. In contrast, atonal music is music that lacks a tonal center or key, and each note is valued in the same way.

From about 1908 onwards atonality has been used in compositions. Composers such as Scriabin, Debussy, Bartók, Hindemith, Prokofiev, and Stravinsky have written music that has been described, in full or in part, as atonal.

In the same way as there exists music that can be described as partly atonal, one can wonder if, in tonal music, a gradation of tonality can be found. One could argue for example that, within the category of tonal music, music written by Bach is, on average, more tonal than music written by Debussy. In this paper we will show that it is possible to make distinctions in tonality in a computational way.

The method that we will use to investigate these gradations of tonality is based on the notion of pitch class sets (hereafter pc-sets). Pc-sets have been used before as a tool to analyze atonal music [11]. Relations between pc-sets, such as transposition and inversion, have been formalized and even similarity measures have been proposed [15, 16, 20, 21, 25]. With our method, we propose a new approach to analyze music by using pc-sets, that may be valuable by providing statistical information about pieces of music. Furthermore, the approach has possible applications in several research areas, among others in automatically separating tonal from atonal music, automatically distinguishing music in a major key from music in a minor key, finding degrees of tonality, music classification, and possibly more.

Modeling tonality has been done in different ways [3, 26], however, to the best of our knowledge, no attempt has been made to measure degrees of tonality. Style classification of music has been investigated using several different methods [4, 18, 22], ranging from statistical [2, 5, 6, 27] to machine learning [8, 13] approaches. It will be worth investigating the possibilities of formalizing the degrees of tonality as a tool for classification of musical style or period. Furthermore, there are, to the best of our knowledge, no methods based on pc theory for classification of music in major/minor mode and classification in tonal/atonal music.

The rest of this paper is organized as follows. Section 2 explains the notion of pc-set categories and motivates the type of research questions that can possibly be addressed with this tool. In section 3 we will show that the (average) category distribution for tonal music differs from the (average) category distribution for atonal music. In section 4, we will show that the category distribution for music in a major key differs from the category distribution for music in a minor key. Section 5 explores the question of whether a degree of tonality can be found when investigating category distributions of music from different musical periods. Finally, section 6 gives concluding remarks.

2. CATEGORIES OF PITCH CLASS SETS

A pc-set [10] can represent both a melody and a chord since no distinction is made between notes at different onset times. Despite these simplifications, pc-sets have proven to be a useful tool in music analysis [24]. If one exhaustively lists all pc-sets (351 in total), all possible melodies and chords can fit in this list. It has been shown that all pc-sets can be grouped into six different categories [14, 19]. This can be done by applying a cluster analysis [19] to several similarity measures [15, 16, 20, 21, 25] for pc-sets.

Each pc-set category corresponds to a cycle of one of the six interval classes. This can be understood in the fol-

lowing way. A cycle of the interval 1 will read: 0,1,2,3,4, etc. A cycle of the interval 2 will read: 0,2,4,6, etc. A cycle of the interval 3 will read: 0,3,6,9, etc., and so on. Since we only take into account the first six of all twelve pitch classes (the latter six are just the inverses), six different cycles appear (see Table 1). Every category turns out to have its own character resulting from the intervals that appear most frequently, and sets of notes that belong to the same category are 'similar' in this respect.

A prototype can be identified for each category. If a certain pc-set is grouped into a certain category, this pc-set can be said to be similar to the prototype of that category. The set $\{0, 1, 2, 3, 4\}$ is the prototype of the Interval Category 1 (IC1) in the pentachord classification, the set $\{0, 2, 4, 6, 8\}$ the prototype of IC2, and so on. The cycles of IC's that have periodicities that are less than the cardinality of their class (for example, pc 4 has a periodicity of 3: {0,4,8}) are extended in the way described by Hanson [12]: the cycle is shifted to pc 1 and continued from there. For example, the IC-6 cycle proceeds $\{0, 6, 1, 7, 2, 8...\}$ and the IC-4 cycle proceeds $\{0, 4, 8, 1, 5, 9, 2, ...\}$. Thus for every cardinality, a separate prototype characterizes the category. For example, category IC4 has prototype $\{0, 4\}$ for sets of cardinality 2, prototype $\{0, 4, 8\}$ for set of cardinality 3, and so on. Table 1 gives an overview of the prototypes of pc-set categories. Prototypes can been listed for duochords to decachords. Pc-sets with less than 2 notes or more than 10 notes can not be classified. This is because one pc-set of cardinality 1 exists, $\{0\}$, and it belongs equally to every category. The same is true for cardinality 11: only one prime form pc-set exists: $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$ and belongs to every category equally. The pc-set of cardinality 12 contains all possible pitch classes.

2.1 Music analysis using pc-set categories

Each category can be seen as having a particular character resulting from the intervals that appear most frequently. Interval category 1, or category 1 for short, consists of all semitones and is the category of the chromatic scale. Category 2 is the category of the whole-tones or whole-tone scale. Category 3 is the category of the diminished triads or diminished scale. Category 4 is the category of the augmented triads or augmented scale. Category 5 is the category of the diatonic scale. Category 6 is the category of the tritones or D-type all-combinatorial hexachord (see [12]).

Because of the typical character of each of the categories, these categories can 'tell' something about the music in which they appear. If a piece of music is dominated by a particular category, the music is likely to broadcast the character of that category.

Ericksson [9] already argued that music can be divided into categories similar to the ones described above and says that "it is often possible to show that one region [category] dominates an entire section of a piece". Our approach goes further in that we fully formalize and automate these categories. When a piece of music is segmented, the category of each segment can be calculated and the distribution of categories for that piece can be presented. The category distribution of a piece of music can present information about this piece that is possibly new and can lead to new insights on specific music. Furthermore, this information may lead to methods for automatic differentiation of music in a major key from music in a minor key, automatic classification of tonal/atonal music, and style classification [2, 5, 6, 27]. Since a pc-set category is by definition a category that consists of similar pc-sets [14, 19], these categories are also expected to form a useful tool in the research area of music similarity problems [1, 7, 17, 21, 23, 28, 29, 31].

2.2 Derivation of category distributions

The method has been implemented in Java, using parts of the Musitech Framework [30], and operates on MIDI data. The MIDI files are segmented at the bar level, as a first step to investigate the raw regularities that occur on this level [1]. The internal time signature of the music is recognized by methods of the Musitech Framework, meaning that, if there is a time signature change, the segmentation per bar will correctly continue.

The pitches from each segment form a pc-set. From each pc-set, the interval class vector can be calculated after which the pc-set category can be calculated. This is done as follows. Using Rogers' cosθ [21] as similarity measure we calculate the similarity to all prototypes of the required cardinality. The prototype to which the set is most similar, represents the category to which the set belongs [14]. However, if the pc-set that is constructed from a bar contains less than 2 or more than 10 different pitch classes, the set belongs equally to every category, as we explained before. To overcome this problem, the segmentation is changed as follows. If a set (bar) contains more than 10 different pitch classes, the bar is divided into beats and the beats are treated as new segments. If a set contains less than 2 pitch classes, this set is added to the set that is constructed from the next bar, forming a new segment. In this way, the number of occurrences of the categories can be obtained, taking into account all pitches in the MIDI file. The number of occurrences of all categories can be presented as percentages, making comparison to other music possible.

3. TONAL VERSUS ATONAL

Every category represents a particular character; thus it can be expected that different types of music will show a different occurrence rate for each category. Since category 5 is the category of the diatonic scale, we expect the occurrence rate of category 5 to be high for tonal music. Choosing a data set [2] of tonal music, the overall category distribution can be calculated as we explained in the previous section.

[1] Preliminary experiments showed that the results following from segmentation per beat, bar or two bars vary only minimally.

[2] Music in MIDI format has been downloaded from the following websites: `http://www.kunstderfuge.com/`, `http://www.classicalarchives.com/`, `http://www.classicalmidiconnection.com/`, `http://www.musiscope.com/`, and `http://www.classicalmusicmidipage.com/`.

(Interval) Category	prototypes (pc sets)				‘character’ of category
IC1	$\{0,1\}$,	$\{0,1,2\}$,	$\{0,1,2,3\}$,	etc.	semitones
IC2	$\{0,2\}$,	$\{0,2,4\}$,	$\{0,2,4,6\}$,	etc.	whole-tones
IC3	$\{0,3\}$,	$\{0,3,6\}$,	$\{0,3,6,9\}$,	etc.	diminished triads
IC4	$\{0,4\}$,	$\{0,4,8\}$,	$\{0,1,4,8\}$,	etc.	augmented triads
IC5	$\{0,5\}$,	$\{0,2,7\}$,	$\{0,2,5,7\}$,	etc.	diatonic scale
IC6	$\{0,6\}$,	$\{0,1,6\}$,	$\{0,1,6,7\}$,	etc.	tritones

Table 1. Prototypes expressed in pc-sets for the six categories. Prime forms have been used to indicate the prototypes (therefore IC5 may appear differently than one may expect).

composer	**piece**
Bach	Brandenburg concerto no. 3
Mozart	Piano concerto no. 5 part 1
Beethoven	Piano sonata Pathetique
Brahms	Clarinet quintet part 1
Mahler	Symphony no. 4 part 1
Debussy	Nocturnes: Nuages

Table 2. The tonal music that was used to calculate Table 3.

category	number of occurrences	percentage of occurrence	standard deviation
1	54	3.22 %	2.09 %
2	83	4.96 %	5.96 %
3	321	19.16 %	8.48 %
4	247	14.75 %	8.33 %
5	890	53.13 %	19.21 %
6	80	4.78 %	2.50 %

Table 3. Distribution of categories in tonal music listed in Table 2.

Table 2 lists the tonal music that has been used for this experiment and Table 3 gives the percentages of occurrences of the categories that are found in this corpus. We see from Table 3 that the music is dominated by category 5. We indeed expected a high occurrence rate of category 5, as this is the category that represents the diatonic scale. However, since the standard deviation is relatively high, the individual percentages vary quite a bit.

For atonal music, we expect a different behavior. We have run the program on strict atonal music composed by Schoenberg, Webern, Stravinsky and Boulez. The complete list of music is shown in Table 4. On average, the distribution as shown in Table 5 was found, using this corpus of atonal music. We can see that the music is not dominated anymore by category 5 but a much more equal distribution is present in atonal music. From the difference in these category distributions, it seems that especially the occurrence of category 5 could contribute to classification methods to separate atonal from tonal music. Cross validation needs to be performed in order to verify this claim. However, since we could find only few MIDI data of atonal music (all MIDI data we found on atonal music is given in Table 4), it is difficult to perform a cross validation with enough data.

composer	**piece**
Schoenberg	Pierrot Lunaire part 1, 5, 8, 10, 12, 14, 17, 21
Schoenberg	Piece for piano opus 33
Schoenberg	Six little piano pieces opus 19 part 2, 3, 4, 5, 6
Webern	Symphony opus 21 part 1
Webern	String Quartet opus 28
Boulez	Notations part 1
Boulez	Piano sonata no 3, part 2: “Texte”
Boulez	Piano sonata no 3, part 3: “Parenthese”
Stravinsky	in memoriam Dylan Thomas Dirge canons (prelude)

Table 4. The atonal music that was used to calculate Table 5.

category	number of occurrences	percentage of occurrence	standard deviation
1	313	28.25 %	10.56 %
2	117	10.56 %	6.14 %
3	166	14.98 %	7.68 %
4	179	16.16 %	7.97 %
5	138	12.45 %	7.15 %
6	195	17.60 %	6.20 %

Table 5. Distribution of categories from music of Schoenberg, Webern, Stravinsky and Boulez.

4. MAJOR VERSUS MINOR

The tonality turns out not to be the only factor to influence the percentage of occurrence of category 5 in music. If we focus on tonal music, an obvious difference can be measured in the occurrence of category 5 between music in major and in minor mode. To show this behavior, we have chosen Bach’s Well-tempered Clavier book I as test corpus and divided the corpus in two parts: 1) the pieces in a major key, and 2) the pieces in a minor key. From Table 6 we can see the differences in category distribution between the two parts and the overall corpus. The pieces in major mode have an average percentage of occurrence of category 5 of 79.81 %, while for the pieces in minor mode this percentage is considerably lower, namely 53.58 % (see Table 6). As one can see, the standard deviations in Table 6 for the music separated in major and minor are smaller than for all pieces together, which means that the measurements are distributed closer around their mean. We can now understand that the standard deviation in Table 3 was relatively large since the data contained both data in major and in minor mode. Reconsidering the results of the previous section, the average percentage of occurrence of category 5

category	occurrences for pieces in **major**	standard deviation	occurrences for pieces in **minor**	standard deviation	occurrences for **all** pieces	standard deviation
1	(31) 2.30 %	1.03 %	(85) 4.48 %	2.22 %	(116) 3.57 %	2.12 %
2	(25) 1.86 %	1.69 %	(98) 5.16 %	2.29 %	(123) 3.79 %	2.63 %
3	(149) 11.06 %	3.23 %	(453) 23.87 %	3.72 %	(602) 18.55 %	7.23 %
4	(47) 3.49 %	3.22 %	(199) 10.48 %	3.73 %	(246) 7.58 %	4.93 %
5	(1075) 79.81 %	6.52 %	(1017) 53.58 %	3.63 %	(2092) 64.47 %	13.87 %
6	(20) 1.48 %	1.24 %	(46) 2.42 %	1.75 %	(66) 2.03 %	1.63 %

Table 6. Distribution of categories in percentages (the number in given between brackets) from the pieces in major mode, and minor mode, and all pieces together, from Bach's Well-tempered Clavier book I.

composer	percentage of occurrence of category 5 for **major** mode	standard deviation	percentage of occurrence of category 5 for **minor** mode	standard deviation
Palestrina	71.94 % *	4.55 %		
Bach	85.71 %	3.99 %	57.72 %	11.02 %
Mozart	58.17 %	7.75 %	37.94 %	6.04 %
Beethoven	47.98 %	6.62 %	36.09 %	7.66 %
Brahms	40.79 %	1.42 %	40.11 %	4.55 %
Mahler	53.83 %	18.33 %	35.95 %	9.24 %
Debussy	68.01 %	5.24 %	40.57 %	9.23 %
Stravinsky	27.65 % *	3.83 %		

Table 7. The percentage of occurrence of category 5 for several composers, separating music in a major and minor key. * For Palestrina and Stravinsky, the separation between music in major and minor mode has not been made (see text for details).

in the music in minor mode of Table 6 is still considerably higher than the average percentage of occurrence of category 5 in atonal music, where one cannot speak of major or minor mode. Moreover, the tonal data from the previous section contained nearly as much music in major mode as music in minor mode. We have to remark, however, that in general, many pieces of music contain segments in both major and in minor mode, although an overall piece is said to be in either major or minor. In our method, we have classified the pieces of music only in a global way (based on the mode of the overall piece), motivated by the consensus that a piece of music in a specific mode will usually contain a majority of segments that are in that mode.

It is understandable that music in minor mode exhibits a lower percentage of category 5 than music in major mode, for the reason that category 5 is the category of the diatonic (major) scale. Although the natural minor scale is diatonic as well, in music in a minor key, other variants like the melodic and harmonic minor scale are frequently used too. For music in minor mode, apart from a high percentage of category 5, categories 3 and to a lesser extent category 4 represent relatively high percentages as well. In contrast, the atonal music has also relatively high percentages of categories 1, 2 and 6. The raised percentage of category 3 for tonal music in minor mode may be explained from the presence of the minor third, and the raised percentage of category 4 from the presence of the minor sixth.

The example in this section shows that for a particular type of music, measuring the percentage of occurrence of category 5, would enable to make a distinction between music in major and in minor mode.

5. DEGREE OF TONALITY?

In the previous sections, we have seen that of all categories, especially category 5 can give some information about both the tonality and the mode. It may be worth to focus on this category for specific composers and to study the difference between them. In Table 7 the percentage of occurrence of category 5 is shown for several composers. The composers are ordered chronologically. For two composers, Palestrina and Stravinsky, no separation is made between major and minor mode. A lot of work by Stravinsky is difficult to be labeled as completely major or minor, and some of his later works can even be labeled as atonal. For Palestrina, no separation between major and minor has been made, since in Renaissance music, besides the normal major and minor scales, eight church modes are used as well. For each composer and for each mode (major or minor), on average 5 pieces of music have been selected, such as to form a representative sample that contains the different musical forms (symphonies, chamber music, concertos, etc.) present in the repertoire of the composer.

Based on the result from section 3 stating that tonal music contains a higher percentage of category 5, we might expect a decreasing percentage of category 5 when the composers are ordered chronologically. For example, one might label Bach as more tonal than for example Mahler since the latter composer would be closer in time to the contemporary period in which the atonal music flourished. This hypothesis turned out not to be true however. It is indeed the case that Bach embodies a higher percentage of category 5 than Mahler, but if we focus on the composers for whom a distinction was made between major and minor music, we see a decreasing percentage of category 5 from Bach to

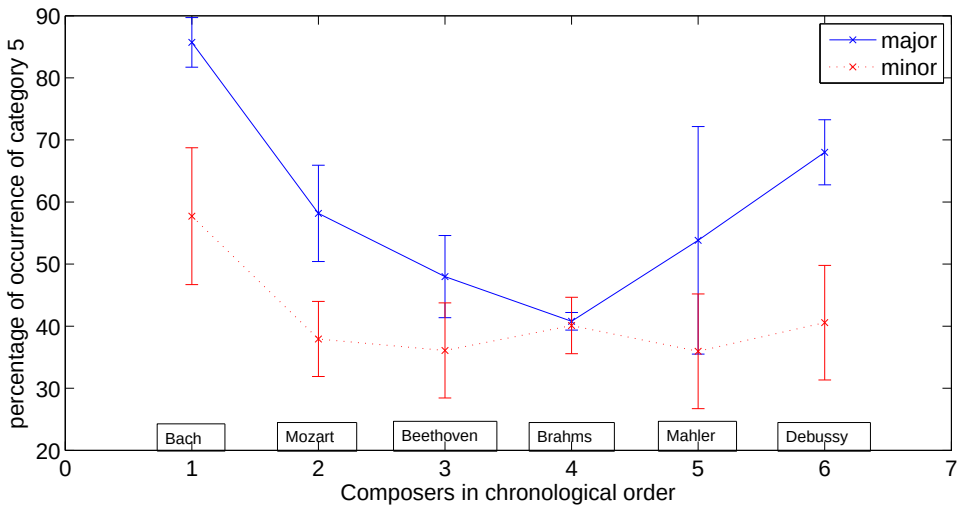

Figure 1. The percentage of occurrence of category 5 for most composers from Table 7, in chronological order. The error bars represent the standard deviation from Table 7.

period	percentage of occurrence of category 5	standard deviation	percentage of occurrence of category 5	standard deviation
Baroque	Bach 85.71 %	3.99 %	Händel 77.40 %	4.64 %
Romantic	Beethoven 47.98 %	6.62 %	Schubert 45.94 %	7.36 %
Impressionist	Debussy 68.01 %	5.24 %	Ravel 40.96 %	14.14 %

Table 8. The percentage of occurrence of category 5 for different composers from the same musical period.

Brahms (focusing on major mode), although from Brahms to Debussy the percentage of category 5 increases again, see Figure 1.

Based on the result from section 4 we expect higher percentages of category 5 for major music than for minor music for each composer. Indeed, this turns out to be the case (see Table 7), although the difference is very small for Brahms.

One could now wonder whether the results of Table 7 show a general behavior that is typical for composers from different musical periods from Renaissance to modern, or that the results are just specific for these composers. We study the differences between composers who lived in the same period, since this might explain the results of Table 7 a bit further. We have zoomed in on music in major mode in three different musical periods, namely the Baroque, Romantic and Impressionist periods (see Table 8) and looked at the difference between two composers within the same period. One can see that for the Baroque and Romantic period, the percentages of category 5 are very much alike for the two composers chosen. However, for the Impressionist period there is a substantial difference between the percentages.

The finding that each composer represents a typical percentage of occurrence of category 5 can possibly be used in applications for style recognition.

6. CONCLUDING REMARKS

In this paper, a new analysis method for music has been proposed, and we explored a number of possible applications. We showed that the six pc-set categories [14, 19] can reveal specific information about music. When music is segmented, and when for each bar is calculated to which category its pc contents belongs, the percentages of the different categories can reveal information about the tonality of the piece (tonal or atonal) and the mode of the piece (major or minor). In particular, category 5, which represents the major diatonic scale, is indicative of this information.

Although on the basis of the percentage of occurrence of category 5, a separation between tonal and atonal music may be made, it does not allow us to order specific music in time. More research needs to be done to be able to explore whether the percentage of occurrence of category 5 can be indicative of a certain style or musical period.

We fully recognize that cross validation experiments need to be carried out in order to verify the suggested possibility of using pc-set categories for the purpose of tonal/atonal classification and major/minor classification, but this is hampered so far by a lack of MIDI data especially for atonal music. Furthermore, in future research we hope to be able to perform an actual classification task. Since the tonal/atonal classification and the major/minor classification both de-

pend on the percentage of occurrence of pc-set category 5, this will not be a trivial task.

To conclude, the distribution of pc-set categories can reveal information about music on different levels, and we suggest that they can serve as a new tool in music analysis.

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