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# **Introduction to Musical Corpus Studies**

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**Warning:** This material is still (heavily) under construction and might change throughout the course!

You can help improving the course and [let me know](#) about any errors and inconsistencies that you find or suggest other ways of improving the course.

## Welcome!

These pages present the content of the course “Introduction to Musical Corpus Studies” at the [Institute of Musicology](#), given at [University of Cologne](#) in Fall 2020.

In the last two decades *Musical Corpus Studies* evolved from a niche discipline into a veritable research area. The growing availability of digital and digitized musical data as well as the application and development of modern methodologies from computer science, machine learning, and data science cast new light on old musicological questions and generate entirely novel approaches to empirical music research.

Moreover, the general methodological and epistemological approach of Musical Corpus Studies allows to transcend traditional intra-musicological boundaries between its sub-disciplines (historical/systematic/ethnological/...) without sacrificing the respective specific viewpoints and perspectives.

This course offers a fundamental and practical introduction into these topics. It demonstrates, explores, and critically reflects central thematic areas and methods by means of a number of case studies. In the engagement with these topics the course also introduces elementary methods from natural language and music processing, as well as statistics, data analysis and visualization.

The course is aimed at students at the undergraduate level who have little or no empirical background and are curious about quantitative approaches to musicology.



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**CHAPTER  
ONE**

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**ORGANIZATION**

## 1.1 Overview

No.	Date	Time	Room	Topic	Methods
1	Fr., 13.11.2020	16:00- 17:20 Uhr	B	Introduction / Background	
2		17:40- 19:00 Uhr		Folk Songs, Melodies, Pitches and Intervals	frequencies, mean, variance
3	Sa., 14.11.2020	09:00- 10:20 Uhr	B	Jazz Solos, Melodies	Regular Expressions
4		10:40- 12:00 Uhr		Beethoven's string quartets Harmony	<i>n</i> -grams, Markov models
		12:00- 13:00 Uhr		Lunch Break	
5		13:00- 14:20 Uhr		Pop Charts Billboard 100, har- mony,	Clustering, <i>k</i> -means, [Hidden Markov Models]
6		14:40- 16:00 Uhr		Free group work	
7	Fr., 11.12.2020	10:00- 11:20 Uhr	A	Brazilian Choro, harmony, form,	Context-Free Grammars
8		11:40- 13:00 Uhr		19th century piano music, har- mony	Probabilistic CFGs
9	Sa., 12.12.2020	09:00- 10:20 Uhr	B	Malian Percussion Music, rhythm, meter	
10		10:40- 12:00 Uhr		Electronic Music 1950-1990	
		12:00- 13:00 Uhr		Lunch Break	
11		13:00- 14:20 Uhr		Free group work	
12		14:40- 16:00 Uhr		Recapitulation and conclusion	

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<sup>1</sup> A: Alter Seminarraum 1.408; B: Neuer Seminarraum 1.315

## **1.2 Credits**

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**Important:** Ich gehe in der Seminarplanung von 12 Semesterwochen à 2 SWS aus, für das gesamte Blockseminar also 24 SWS. Das Seminar wird mit 3 CP bewertet, was 90 Stunden aktiver Arbeit entspricht. Davon entfallen 24 SWS an die Präsenzzeit im Seminar plus 48 SWS an Vor- und Nachbereitung der Seminarsitzungen. Die verbleibenden 18 SWS sind für die Lektüre der Fachliteratur vorgesehen.

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CHAPTER  
TWO

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INTRODUCTION



## 2.1 About this course

### 2.1.1 About me

- Music and Mathematics education (Uni & HfMT Köln)
- MA Musicology (HfMT Köln)
- PhD Digital Humanities (EPFL)

## 2.1.2 Focus of this course

Programming introductions often boring. A lot of time lost in introducing basic concepts and techniques (important!) but quite remote from actual (!) applications. Examples are usually “toy examples” that work well, but the transition to real-world applications is difficult. Of course, the example studies discussed in this course work well, too. However, they are without exception taken from peer-reviewed, published, open access articles. They thus reflect actual, recent research questions that reflect current research.

This course takes thus the opposite approach to “toy examples”. We will not introduce many specific programming concepts. The course rather showcases what is possible with musical corpus studies. If this sparks your interest, it will be much easier to pick up the basics for yourself, knowing what they are *for* and being motivated intrinsically. If you are not particularly interested in doing this kind of work yourself, you will still see a broad range of applications that are much more useful to you than learning (or not learning) Python basics.

## 2.2 What are Musical Corpus Studies?

tbc... (text from diss?)

## 2.3 Epistemological goals

tbc...

## 2.4 Issues

tbc [Coo06][Hon06][Hur13][Mar16][NR16][Pug15][Sch16][TV13]

## 2.5 MCS and traditional musicology

tbc

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**CHAPTER  
THREE**

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## **FOLK SONGS AND THE MELODIC ARC**

Huron... / MusThe Tutorial

maybe extend with Hansen and Pearce (2014) (but data not available?)



## SOLOS IN THE WEIMAR JAZZ DATABASE



Fig. 4.1: Photo by Janine Robinson on Unsplash

The first project we will have a look at is the [Jazzomat](#) project. Transcriptions of Jazz solos [PFAbesser+17]. The *Weimar Jazz Database* (WJD) consists of 456 transcriptions of Jazz solos from diverse substyles. As all the corpora that we deal with here, it is freely available on the internet.<sup>1</sup>

The WJD contains a number of tables:

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<sup>1</sup> <https://jazzomat.hfm-weimar.de/dbformat/dboverview.html>

Table 4.1: Tables in the *Weimar Jazz Database*

Table name	Description
beats	Table for beat annotation of WJD melodies, referenced by melody (melid)
composition_info	Infos regarding the underlying composition of a WJD solo, referenced by melody (melid)
db_info	Information regarding the distributed database file like version information, license, etc
esac_info	EsAC infos for EsAC melodies, referenced by melody (melid)
melody	Main table for all melody events
melody_type	Indicated type of melody: WJD solos or EsAC (Folk songs using Essen Associative Code), referenced by melody (melid)
popsong_info	Pop song infos, referenced by melody (melid)
record_info	Infos regarding the specific audio recording of a WJD solo was taken from, referenced by melody (melid)
sections	All sections (phrase, chorus, form, chords, etc.), referenced by melody (melid)
solo_info	Solo infos for WJD solos, referenced by melody (melid)
track_info	Information specific to a track on a record (or CD)
transcription_info	Transcription infos for WJD solos, referenced by melody (melid)

Here, we focus on the main table `melody`. First, we download the entire database from <https://jazzomat.hfm-weimar.de/download/download.html> (under “Weimar Jazz Database”) and save it as the file `wjazz.db`.

```
import sqlite3 # for working with databases
import pandas as pd # for working with tabular data

# create connection to database
conn = sqlite3.connect("wjazzd.db")

# read all entries of the 'melody' table into a pandas DataFrame
df = pd.read_sql("SELECT * FROM melody", con=conn)

df.head()

>>> df.head()
output
```

The part of the code `SELECT * FROM melody` reads “Select all entries from the table ‘melody’”.

## HARMONY IN BEETHOVEN'S STRING QUARTETS

### 5.1 Access the data

The data lies on the GitHub repository [DCMLab/ABC](#). Either download the `.tsv` file directly and open it in pandas or load it from the URL as follows:

```
import pandas as pd  
  
df = pd.read_csv("https://github.com/DCMLab/ABC/corpus.tsv", sep="\t")
```

The corpus is now stored in the variable `df`.

### 5.2 Harmonic Annotations

- regular expressions

[NHMR18][MNHM19]

### 5.3 Chord Transitions

- n-grams



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CHAPTER  
SIX

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## HARMONIC CLUSTERS IN POP CHARTS



Clustering analysis in [SVJ+20].

```
def zipf_mandelbrot(x, a, b, c):
    """Zipf-Mandelbrot function of `x` given parameters `a`, `b`, `c`."""
    z = a / ( (b + x)**c )
    return z
```

## 6.1 The dataset

djfjfjf

## 6.2 Research question

Hypothesis: Corpus is not stylistically uniform but consists of several sub-styles, each with respective harmonic sub-grammars.

Discussion: what is harmonic grammar/syntax (Riemann/GTTM/Rohrmeier)

## 6.3 Operationalization

Harmonic grammar → bigrams (we know that already)

## 6.4 Clustering

### 6.4.1 General idea

Variance, minimizing *within-cluster sum of squares*, ...

### 6.4.2 Algorithm

For data  $\mathbf{X} = \{x_1, x_2, \dots, x_n\}$ :

1. Choose  $k \leq n$ .
2. Randomly assign means  $\mu_1, \dots, \mu_k$  to points in  $\mathbf{X}$ .
3. Assign each point in  $\mathbf{X}$  to cluster  $C_i$  by determining closest mean  $\mu_i$ .
4. Given a cluster  $C_i$ , calculate its *centroid*  $m_i$ :

$$m_i = \frac{1}{|C_i|} \sum_{x_j \in C_i} x_j$$

5. Repeat steps 3 and 4 until the means do not change anymore.

Note that, while this is a relatively simple clustering algorithm, it is not guaranteed that it finds the global optimal solution. This means that different *initializations* (step 2 of the algorithm) might lead to different clustering results. More sophisticated clustering methods are, e.g. kNN...

## HARMONY AND FORM IN BRAZILIAN CHORO



Fig. 7.1: A 2019 musical tribute to renowned choro composer Jacob do Bandolim, on the 50th anniversary of his death in Sao Paulo, Brazil. (c) Governo do Estado de Sao Paulo / CC BY 2.0

### 7.1 Data

The *Choro Songbook Corpus* contains transcriptions of the chord symbols of 295 Choro pieces [MSFR20]. It is available on [Zenodo](#) or [Github](#). See this link for a performance of the piece “Lamentos”

As before, we can import our data from a public resource.

```
url = "https://raw.githubusercontent.com/DCMLab/choro/1.1/data/choro.tsv"
df = pd.read_csv(url, sep='\t")
```

And display the first rows of the data frame:

```
df.head()
```

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CHAPTER  
EIGHT

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## A DATA-DRIVEN HISTORY OF TONALITY



### 8.1 Musical Pieces as Tonal Pitch-Class Distributions

Musical pieces are composed of notes which have a certain pitch, a certain duration, and are located in a specific position in a piece. Here, we disregard both the location and the duration of notes and consider only the pitch dimension of musical notes when counting them. It is moreover common to consider notes to be equivalent if their respective pitches are related by one or multiple octaves, and thus to speak of *pitch classes*. Pitch classes come in two varieties. The first, most commonly used representation in computational musicology and music information retrieval, distinguishes twelve different pitch classes. This representation system also assumes the enharmonic equivalence of certain notes, e.g. F♯ and G♭, C♯ and B, etc. The assumption of enharmonic equivalence is usually a consequence of music encoding formats that assume twelve-tone equal temperament, e.g. MIDI, in which enharmonically equivalent notes are indistinguishable. The assumptions of octave and enharmonic equivalence allow to represent pitch classes

as residuals in  $\mathbb{Z}_{12}$  and to arrange them on a circle. This arrangement of pitch classes is shown in Fig. 8.1, called the *circle of fifths*.

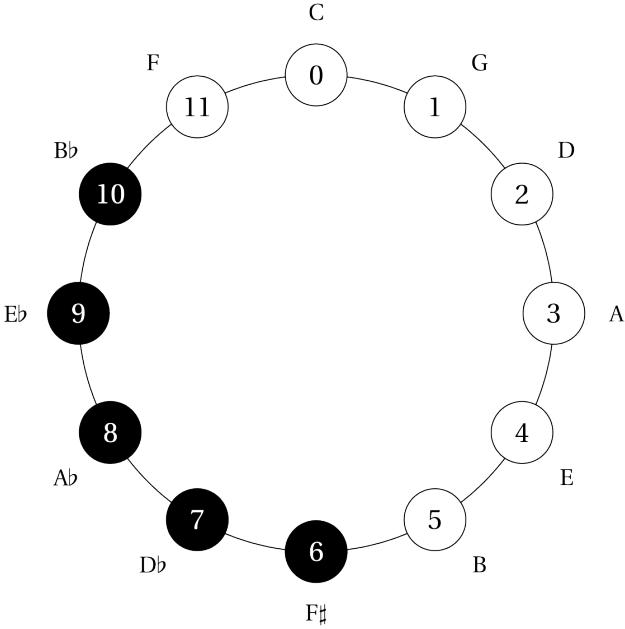


Fig. 8.1: Schematic depiction of the twelve neutral pitch-classes in  $\mathbb{Z}_{12}$  on the circle of fifths. One representative of each neutral pitch-class is shown as a tonal pitch-class label next to the node. The coloring of the nodes corresponds to the colors of the keys on the piano.

The numbers correspond to pitch classes in the order of fifths that can be transformed to chromatic ordering, the chromatic circle, by the mapping  $t \mapsto 7t \bmod 12$ . Pitch classes that correspond to white keys on the piano are shown in white and pitch classes that correspond to black keys on the piano are shown in black. The second variant of pitch classes does not assume enharmonic equivalence but only that octave-related notes are equivalent, and is hence more general. This representation allows to arrange pitch classes on the *line of fifths* [Tem00]. This linear ordering of tonal pitch-classes has been used by a number of music theorists, e.g. [Web51][Rie00][Han48][Bar56]. It is shown in Fig. 8.2.

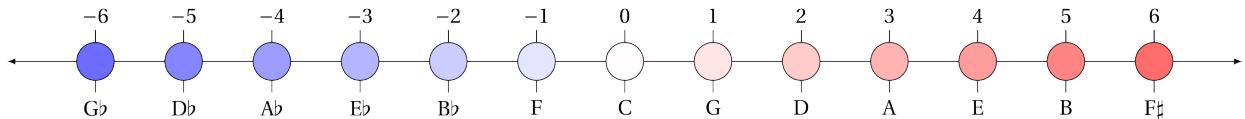


Fig. 8.2: Schematic depiction of the tonal pitch-classes on the line of fifths mapped to integers in  $\mathbb{Z}$ .

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**Tip:** Think of other possible equivalence relations for pitch classes. E.g. which relation do we need to distinguish only two classes, high and low with respect to middle C?

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Following [Tem00], we call the first representation *neutral pitch-classes* and the second one *tonal pitch-classes*. The linear structure of the line of fifths allows to associate each tonal pitch-class with an integer  $k \in \mathbb{Z}$  such that this integer represents the number of perfect fifths that lie between this pitch-class and C (Gárdonyi and Nordhoff, 2002). In other words, the integer  $k \in \mathbb{Z}$  corresponds to the number of flats (negative integers) or sharps (positive integers) that the major key has in which this tonal pitch-class is the root. For example, D is mapped to +2 because D major has a key signature with two sharps, Ab is mapped to -4 because the key signature for Ab major has four flats, and C is mapped to 0 because its key signature does not have any accidentals. Yet another benefit of this representation

can be seen in the way in which we associate each tonal pitch-class with a color. Positive integers ('sharpened' tonal pitch-classes) are associated with increasingly darker shades of red, negative integers are associated with increasingly darker shades of blue ('flattened' tonal pitch-classes), and C is associated with white as the neutral origin of the line of fifths. This color mapping is used throughout this part. The line of fifths does not only contain all tonal pitch-classes but also a number of central musical scales. For example, pentatonic scales are segments of length 4 (containing five pitch classes) on the line of fifths, e.g. from G $\flat$  to B $\flat$ , diatonic scales are defined by segments of length 6, e.g. from F to B, the early extensions of the natural diatonic scale by B $\flat$  and F $\sharp$  correspond to the segment spanning the eight fifths on the line between these two tonal pitch-classes, and the two whole-tone scales correspond to the odd and even numbers, respectively. Theoretically, the line of fifths extends to infinity in both directions but in actual compositions only a small segment of it is used. In the corpus that is used here, we consider only the segment from F $\flat\flat$  to B $\sharp\sharp$  because no piece in the corpus contains tonal pitch-classes outside this range. The vocabulary size of the corpus is thus  $V = 35$ , consisting of the seven natural pitch-classes F, C, G, D, A, E, B with two, one, or zero sharps or flats, respectively. While the transformation of tonal into neutral pitch-classes is achieved by deterministically mapping a tonal pitch-class  $t \in \mathbb{Z}$  to a neutral pitch-class  $t \mapsto t \bmod 12 \in \mathbb{Z}_{12}$  (in fifths ordering), the reverse direction involves some kind of inference and is called the problem of pitch spelling ([Tem01][Cam03][SRU04][CC05][Mer06]).

helix

Due to the encoding of the corpus, we adopt the representation of pieces as bags of notes (see Section~ref{sec:bagofnotes}) and represent each one as a distribution over the  $V = 35$  tonal pitch-classes. That is, in the corpus used here with  $D = 2012$  pieces, the tonal pitch-class distribution of a musical piece  $x_d$  is given by the relative frequencies of the tonal pitch class in that piece, for  $d \in \{1, \dots, D\}$ . Each piece is thus described by a  $V$ -dimensional vector,  $x_d \in \mathbb{R}^V, \forall d \in \{1, \dots, D\}$ , containing positive real numbers that sum to 1. In this chapter, we do not make any further assumptions about the process that generated this distribution and will postpone these considerations until Chapter~ref{chap:tonal\_profiles}.

In this view, pieces simply correspond to points in the  $V - 1$ -simplex

$$\Delta^{V-1} = \left\{ x_d \in \mathbb{R}^V \mid \sum_{i=1}^V x_{d,i} = 1; x_{d,i} \geq 0 \right\}.$$

In this space, those pieces with very different tonal pitch-class distributions will be very distant, whereas pieces that have similar tonal pitch-class distributions will be closer to one another and form clusters in the  $V - 1$ -simplex. It is important to note that the bag-of-notes representation relies on the assumption that the  $V$  dimensions are independent, meaning that this model does not *a priori* assume any particular order between the tonal pitch-classes.

The average tonal pitch-class distribution of all pieces in the corpus is shown in Figure~ref{fig:pca\_mean}. Figure~ref{fig:tpc\_mean\_dist\_periods} in the appendix shows this distribution separately for each century from 1361 to 1943. Although we know that one can in principle order all tonal pitch-classes on the line of fifths (Fig. 8.2), we do not incorporate this assumption into the model but will show instead that it can be inferred from the data.

### 8.1.1 Distributions of TPCs

What are (discrete) distributions?

entropy

**Hypothesis:** similar pieces have similar distributions

operationalization: distances in vector space

Assumption (for coloring): tonal center is approximated by most frequent note

Taking tonal spaces into account: the line of fifths (dimensionality reduction, clustering, t-SNE, PCA)

### 8.1.2 Principle Component Analysis

Since the dimensionality of  $\Delta^{V-1}$  is  $|\{C, D, E, F, G, A, B\}| \cdot |\{\flat\flat, \flat, \natural, \sharp, \sharp\sharp\}| = 35$ , it is impossible to visualize this space and pieces in it to see whether their arrangement contains any meaningful information. We address this problem by using a method for *dimensionality reduction* called *Principal Component Analysis* (PCA) [Bis06] that projects the data into a lower-dimensional space while at the same time maintaining as many characteristic properties of the original space as possible. PCA thus can aid to achieve a better understanding of the global structure of the space.<sup>1</sup>

PCA considers the data to be represented as a matrix

$$X = \begin{bmatrix} x_1^\top \\ \vdots \\ x_D^\top \end{bmatrix} \in [0, 1]^{D \times V}, \quad x_d \in \Delta^{V-1},$$

where the rows are given by the  $D$  data points, the pieces in the corpus, and the columns are given by the  $V$  features, the number of distinct tonal pitch-classes in the vocabulary. All entries in  $X$  range between 0 and 1 and all rows of  $X$  sum to 1 because the pieces are represented as distributions. PCA determines the  $M \leq V$  largest directions and magnitudes of the variance in the data in  $X$  by first calculating the *covariance matrix*

$$K_X = \text{cov}[X, X] = E[(X - \bar{x})(X - \bar{x})^\top] \in \mathbb{R}^{D \times D},$$

where  $E$  denotes the expected value and  $\bar{x} \in [0, 1]^V$  is the mean of the columns of  $X$ . The main directions of the variance in the data and their magnitude is given by the eigenvectors  $w_i$  and eigenvalues  $\lambda_i$  of  $K_X$  which can be calculated by solving

$$K \cdot w_i = \lambda \cdot w_i.$$

The projection into the lower-dimensional space is then achieved by selecting the  $M$  largest eigenvalues and their corresponding eigenvectors and transform the data to  $X'$ , the dimensionality reduction of  $X$  by

$$X' = X \cdot [w_1, \dots, w_M] \in \mathbb{R}^{D \times M}$$

The sum of all eigenvalues  $\lambda_i$  is the total amount of variance in the data and the variance explained by each principal component is given by  $\lambda_i / \sum_j \lambda_j$ .

In the present context,  $X$  was transformed to have zero mean before applying PCA but that the variance was not standardized to 1. This was done because the features all are on the same scale and because the differences in the variance between the respective tonal pitch-classes is of particular interest here.

## 8.2 Historical Development

historical expansion on line of fifths,

---

<sup>1</sup> While PCA is one of the most commonly used methods for dimensionality reduction, there are many others (sometimes relying on particular assumptions about the distribution of the data). In a qualitative comparison, *Locally Linear Embedding* [RS00] achieved a similar picture, whereas *t-distributed Stochastic Neighbor Embedding* (t-SNE) [VDMH08] that does emphasize the local over the global structure of the data did not. We opted here for PCA because it preserves most of the global structure and the interpretation of the results is straight-forward.

### 8.2.1 LOWESS



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CHAPTER  
NINE

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## MALIAN PERCUSSION MUSIC



Fig. 9.1: Studio session in Bamako, May 2007. Left to right: Madu Jakite (Dundun), Sedu Balo (first Djembe) und Drissa Kone (second Djembe). Photo taken from <https://www.gmth.de/zeitschrift/artikel/908.aspx>.

Reproduce results from [LPJ17]. (Essentially same study in [P JL16])



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CHAPTER  
**TEN**

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## ELECTRONIC MUSIC 1950–1990



Fig. 10.1: Photo by Antoine Julien on Unsplash.



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**CHAPTER  
ELEVEN**

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**CONCLUSION**

Final thoughts, critical discussion...

[Some image]



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