# Ontology based Music Theory
## Knowledge Engineering Project & Project Work

**Alessia Deana**
Master's Degree in Artificial Intelligence, University of Bologna
{alessia.deana}@studio.unibo.it

### Abstract

This project presents the development of an ontology and knowledge graph aimed at modeling key concepts in musicology, specifically focusing on musical cadences. The ontology formalizes the structure and relationships of various cadence types, including Perfect, Imperfect, Deceptive, Plagal, Half, and Avoided cadences. Designed for the analysis of musical compositions, the ontology has been applied to the Winterreise compositions of Franz Schubert, utilizing data from the CHOCO dataset. By mapping chords, degrees, keys, and structural sections of a piece, this ontology enables a detailed examination of cadential patterns and their role in musical form. The ontology was visualized using Graffoo in draw.io, and the data was analyzed through a custom Python notebook.

## 1 Introduction

The purpose of this project is to develop an ontology and an knowledge graph aimed at modeling fundamental musicological theories, with a specific emphasis on musical cadences. Cadences, which are key elements in harmonic progression, play a vital role in shaping the structure and flow of musical compositions. By formalizing these cadential phenomena, the ontology offers a structured, machine-readable framework that allows for detailed analysis of harmonic sequences and the function of cadences within tonal music.

This ontology has been designed specifically to facilitate the analysis of musical compositions, focusing on the CHOCO dataset. This dataset includes a wide range of musical works, with special attention in this project given to Schubert's Winterreise files. These compositions provide a rich source of musical data, making it possible to explore cadential patterns and harmonic progressions in a real-world musical context.

## 2 Background

In music theory, a cadence is a sequence of chords that brings a musical phrase to a conclusion. Cadences are essential in shaping the structure and flow of a piece of music, providing moments of rest or resolution, and signaling the end of a section or phrase. Depending on the type, cadences can create a sense of closure, continuation, or surprise. How to identify a Cadence Cadences typically occur at the end of musical phrases, where there is a change or resolution in harmonic tension. To identify a cadence, one must analyze the harmonic progression, focusing on the last two chords of a phrase. The scale degree (also called degree) of the chord in relation to the key of the piece is crucial in identifying the type of cadence. A scale degree refers to the position of a note or chord relative to the tonic (the first note of the scale). Each chord is assigned a Roman numeral, with I representing the tonic (1st degree), V representing the dominant (5th degree), and so on. For example, in the key of C major:

- The I chord (tonic) is C (C-E-G),
- The V chord (dominant) is G (G-B-D),
- The IV chord (subdominant) is F (F-A-C).

Types of Cadences Several types of cadences can be identified based on the progression between the final two chords. The most common types include:

- Perfect Authentic Cadence (PAC): This cadence is the most conclusive, offering a strong sense of resolution. It occurs when a dominant chord (V) resolves to the tonic (I), both in root position (the root note is the lowest note of the chord) and with the tonic note in the melody. For example, in C major, a G (V) to C (I) progression is a perfect authentic cadence.

- Imperfect Authentic Cadence (IAC): Similar to the PAC, the IAC also involves a dominant (V) to tonic (I) resolution, but either one or both of the chords may be inverted (i.e., not in root position), or the tonic is not in the highest voice. This cadence creates a weaker resolution than the PAC.

- Deceptive Cadence (DC): A deceptive cadence occurs when a dominant chord (V) resolves unexpectedly to a chord other than the tonic, often the submediant (vi). This creates a feeling of surprise and postpones the expected resolution. For instance, in C major, a G (V) resolving to A minor (vi) forms a deceptive cadence.

- Plagal Cadence (PC): Known as the "Amen cadence" due to its frequent use in hymns, a plagal cadence occurs when the subdominant (IV) moves to the tonic (I). In C major, this would be an F (IV) to C (I) progression. It is a softer and less final cadence compared to the PAC.

- Half Cadence (HC): A half cadence ends on a dominant chord (V), leaving the phrase open and unresolved. It is often used as a point of tension that needs to be resolved in the subsequent phrase. For example, a progression from C (I) to G (V) in C major is a half cadence.

- Avoided Cadence (AC): The avoided cadence is a type of cadence where the resolution is deliberately interrupted, avoiding the expected resolution to the tonic. This often occurs when a V chord resolves to something other than the tonic, such as to a non-dominant degree or a distant chord. While similar to a deceptive cadence, the avoided cadence often leaves the phrase unresolved or leads to another unexpected progression.

## 3 System description

The system was developed by first creating an ontology in RDF/XML format to represent musical cadences and their relationships within a composition. The ontology was then visualized using the Graffoo library (available at Graffoo), which was integrated with the draw.io tool to create a clear graphical representation of the ontology's structure.

Following the creation and visualization of the ontology, a Python notebook was developed to analyze the musical data. This notebook allowed for querying the ontology and extracting insights related to cadential patterns and harmonic progressions, particularly from the Schubert Winterreise files within the CHOCO dataset. The Python environment facilitated the automation and detailed analysis of the data, utilizing SPARQL queries to explore the relationships between cadences, keys, and chords in the compositions.

## 4 Data

The data used in this project consists of musical compositions from Franz Schubert's Winterreise, sourced from the CHOCO dataset. The dataset provides detailed annotations in the JAMS (JSON Annotated Music Specification) format, which allows for a rich set of musical features, including chord progressions, key changes, and section segmentation, to be captured and analyzed.

Each JAMS file within the dataset represents an individual piece from Winterreise. For example, the file for Gute Nacht, the opening song in the cycle, contains annotations regarding:

- Chords: Captures harmonic progression with chord names, durations, and additional confidence scores. For instance, it identifies chords like "C:min," "F:min7," and "G:7."

- Keys: Key annotations, such as "C:min" or "D#:maj," capture the overall harmonic environment of the piece and any modulations.

- Sections: Structural divisions like "A," "B," "C," and their respective time durations allow the analysis of how harmonic and cadential features relate to different musical sections.

Through the integration of these JAMS files with the ontology, it becomes possible to systematically analyze the cadential patterns across different sections of the compositions.

## 5 Ontology Description

The ontology created for this project models the structure and relationships of musical cadences in a formal and machine-readable format. It serves as the backbone for analyzing harmonic progressions and cadential phenomena in musical compositions.

At the core of the ontology is the **Cadence** class, which represents various cadence types. These

types are modeled as specific subclasses, such as *Perfect*, *Imperfect*, *Deceptive*, *Plagal*, *Half*, and *Avoided*. Each subclass corresponds to a distinct cadential category, allowing for detailed classification and analysis.

The ontology includes other several key classes:

**Chord**: Represents the harmonic building blocks of cadences, which are linked to the Degree class.

**Degree**: This class captures the harmonic function (e.g., tonic, dominant) within the context of a cadence. Each Degree is linked to a Chord via the *hasChord* property and to a Key via the *hasKey* property.

**Key**: Represents the tonal context in which the cadences occur, allowing for the analysis of cadences in different keys.

**Section**: Refers to structural parts of a composition, such as verses or choruses. The *belongsToSection* property links a cadence to the section in which it appears.

The relationships between these classes are fundamental for capturing the cadential context. For example:

Cadence is linked to its preceding and following harmonic degrees via the *hasPrecedingDegree* and *hasFollowingDegree* properties. This enables the identification of harmonic progressions leading into and out of a cadence.

Degree is connected to both Chord and Key through the *hasChord* and *hasKey* properties, which detail the specific harmonic content and tonal context of a given degree.

Cadence is further linked to a Section through the *belongsToSection* property, which helps situate cadences within the overall structure of a musical piece.

This ontology has been designed with flexibility in mind, making it suitable for a wide range of musical works and adaptable for future extensions. It has been specifically applied to analyze cadential structures in Schubert's Winterreise, providing a comprehensive framework for examining cadences in the context of tonal music.

## 6 Data Analysis Approach

This project involved the analysis of harmonic structures and cadences in Schubert's Winterreise compositions from the CHOCO dataset. The dataset provided the musical sections, along with their respective start and end times. The analysis focused on examining the chords within each section and identifying cadences by concentrating on the chords occurring near the end of the section. A filtering approach was applied to consider only those chords that ended shortly before the section's conclusion, ensuring that the selected chords were part of the cadential progression at the section's boundary.

To determine the harmonic degree of a chord relative to the key, I create a function that takes a chord and a key as input, extracting the root note of the chord (ignoring any inversions or alterations). Once the note is identified, the function checks whether the key is major or minor and selects the appropriate reference scale (major or minor).

If the key is major, the diatonic major scale is used; for minor keys, the diatonic minor scale is applied The function then looks for the chord's root note in the selected scale. If the note is found, it returns the corresponding degree using a mapping of degrees (I, II, III, IV, V, VI, VII). If the note is not present in the scale, the function returns None, indicating that the chord's degree cannot be determined for that key.

## 7 Results and Conclusion

The analysis of cadences in the data has revealed interesting patterns in both the distribution and types of cadences across different sections and keys.

**Section Analysis**: In the first graph (Figure 1), we can observe the number of cadences identified in each musical section. Sections like *section_A*, *section_B*, and *section_I* display a high concentration of cadences. In particular, section A features a significant number of Cadence and Half Cadence types, with fewer occurrences of Imperfect and Perfect cadences.

In contrast, sections such as section_A3, section_C2, and section_I2 contain far fewer cadences. This suggests that the harmonic activity, particularly cadential closure, is more prominent in certain sections of the composition. The varying cadence distributions indicate that different sections may serve unique harmonic functions—some emphasizing resolution (with more Perfect Cadences) and others driving tension or continuation (with Half Cadences or fewer cadences overall).

However, it is important to note that a large number of cadences, such as those in Section A1 and Section I, were not categorized into

specific types but were instead labeled simply as "Cadence."

**Key Analysis**: When analyzing cadences by key, the data revealed some interesting trends (Figure 2). key_C_min stands out for its high number of Half Cadences and Avoided Cadences, suggesting a tendency towards unresolved or open-ended harmonic phrases in this key. In contrast, keys like key_G_min and key_C_maj exhibit a more even distribution of Perfect, Half, and Cadence types, indicating a more balanced use of cadential resolution.

Moreover, some keys, such as key_D_maj, display a higher concentration of Perfect Cadences, emphasizing conclusive harmonic progressions. This key-specific variation could reflect Schubert's compositional choices to evoke different emotional or structural effects in Winterreise through harmonic tension and resolution.

The varied distribution of cadence types across different keys emphasizes how the harmonic structure of Schubert's compositions shifts depending on the tonal center. The dominance of minor keys, combined with their richer harmonic variety, reflects the emotional depth of Winterreise, with cadences playing a critical role in shaping the tonal narrative.

**Perfect Cadences: A Detailed Analysis**: A closer examination of Perfect Cadences shows recurring patterns of chord progressions. For example, in key_F#_min, the progression from chord_C# (3,5,b7) to chord_F# (3,5) occurred 8 times, while in key_G_min, the dominant-to-tonic progression from chord_D (3,5) to chord_G (3,5) occurred 16 times.

These repetitive harmonic structures underline the importance of dominant-tonic relationships in Schubert's music, particularly in reinforcing phrase endings. The Perfect Cadence, characterized by a resolution from the dominant (V) to the tonic (I), serves as a powerful tool for providing closure and establishing key areas. The recurrence of specific chord pairs across various instances confirms the reliance on traditional harmonic resolution techniques.

The heatmap (Figure 3) further illustrates these recurring chord patterns, providing visual confirmation that Perfect Cadences often involve familiar harmonic progressions. This consistency supports the idea that Schubert relies on certain harmonic formulas, particularly in cadential moments, to anchor the musical form.

**Unidentified Cadences**: A notable portion of cadences in the dataset were not categorized under a specific type and were instead classified generically as "Cadence." There are several potential reasons for this:

- Undeclared categories: Some harmonic progressions might not fit neatly into established cadence types. This could be due to Schubert's use of more ambiguous or unconventional harmonic structures, especially in transitional passages where the cadence is less clear-cut.

- Difficulty in determining harmonic degree: In some cases, the algorithm was unable to determine the harmonic degree of a chord relative to the key, either due to incomplete harmonic data or the complexity of the harmonic progression. For example, if a chord does not fit within the expected diatonic scale, it may not be possible to assign it a degree, resulting in its exclusion from standard cadence categories.

In conclusion, the analysis of Schubert's Winterreise highlights the central role of cadences in shaping the harmonic landscape of the compositions. Perfect Cadences emerged as the dominant type, particularly in minor keys, where they serve to reinforce tonal centers and provide strong closures to musical sections. However, a significant number of cadences were left uncategorized, underscoring the challenges of analyzing music that often operates outside the bounds of traditional harmonic categories.

This suggests that while many cadences can be classified with existing theoretical tools, Schubert's harmonic language often pushes these boundaries, requiring a more nuanced approach to understanding and categorizing cadential structures.

## 8 Links to external resources

Link to the GitHub repository: ke_projects.git

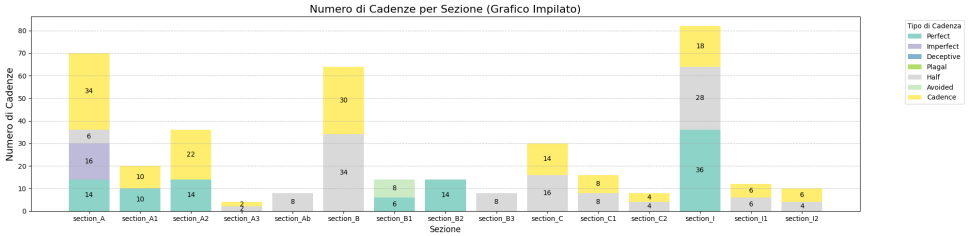


Figure 1: Cadence count per section

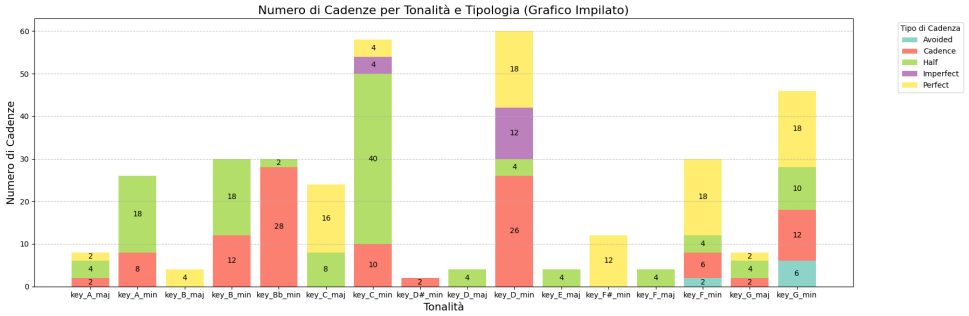


Figure 2: Cadence count per key

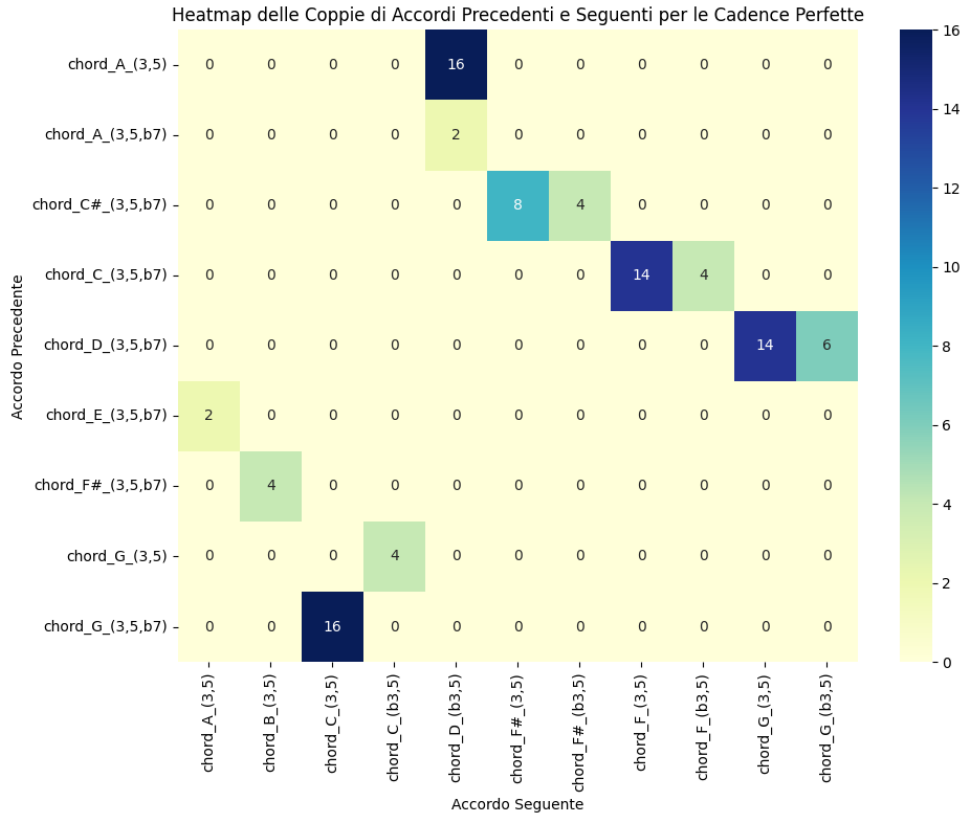


Figure 3: Heatmap of Preceding and Following Chord Pairs for Perfect Cadences