Semantic Web Technologies in the Music Domain

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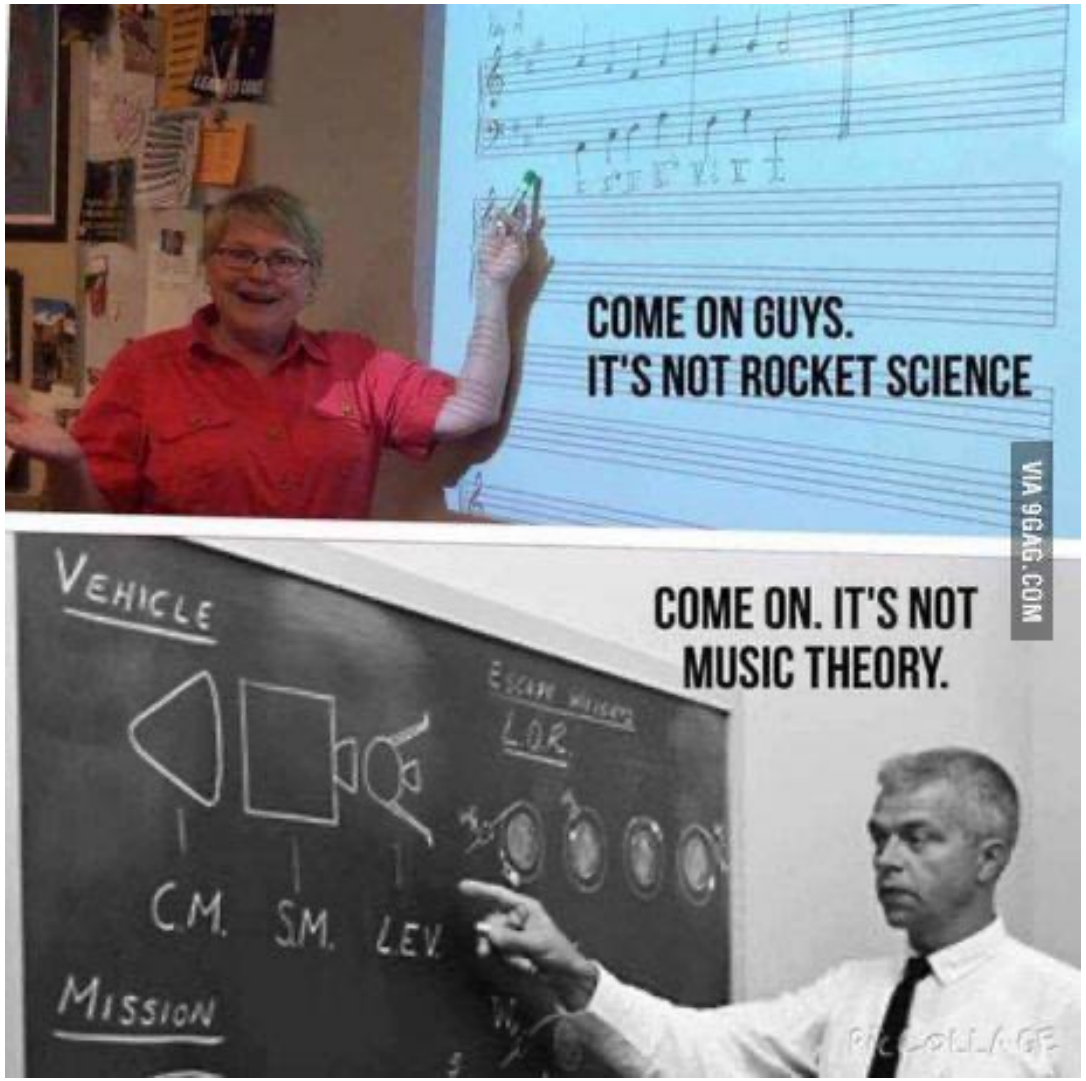
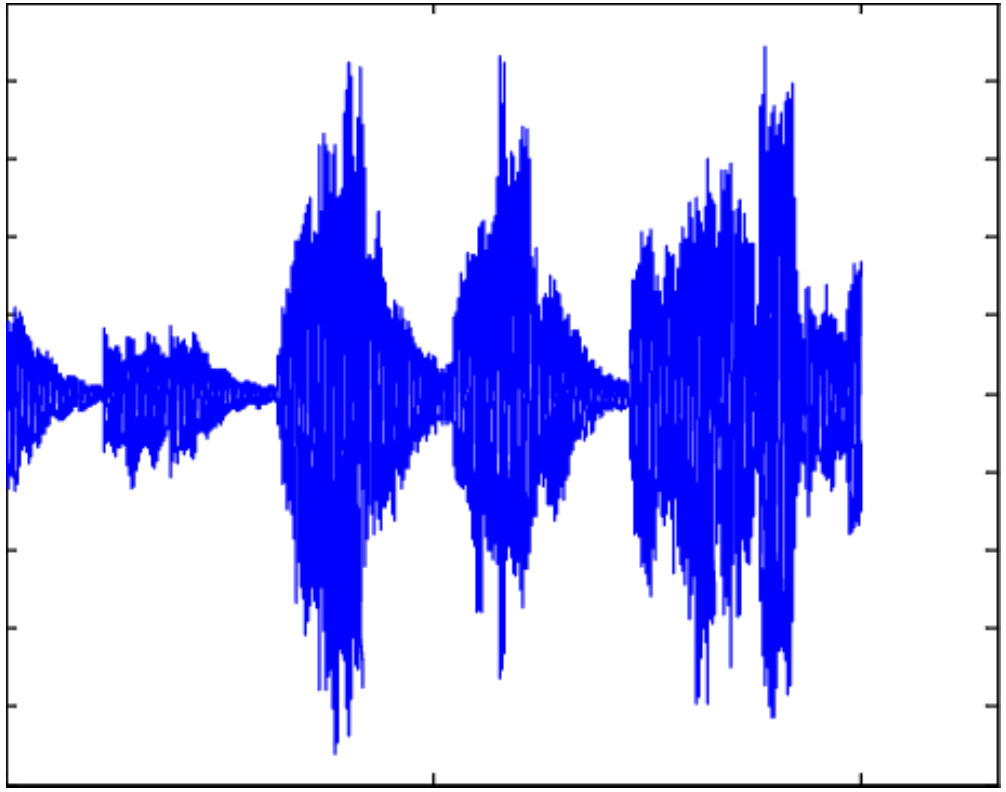
01

MUSICAL BACKGROUND

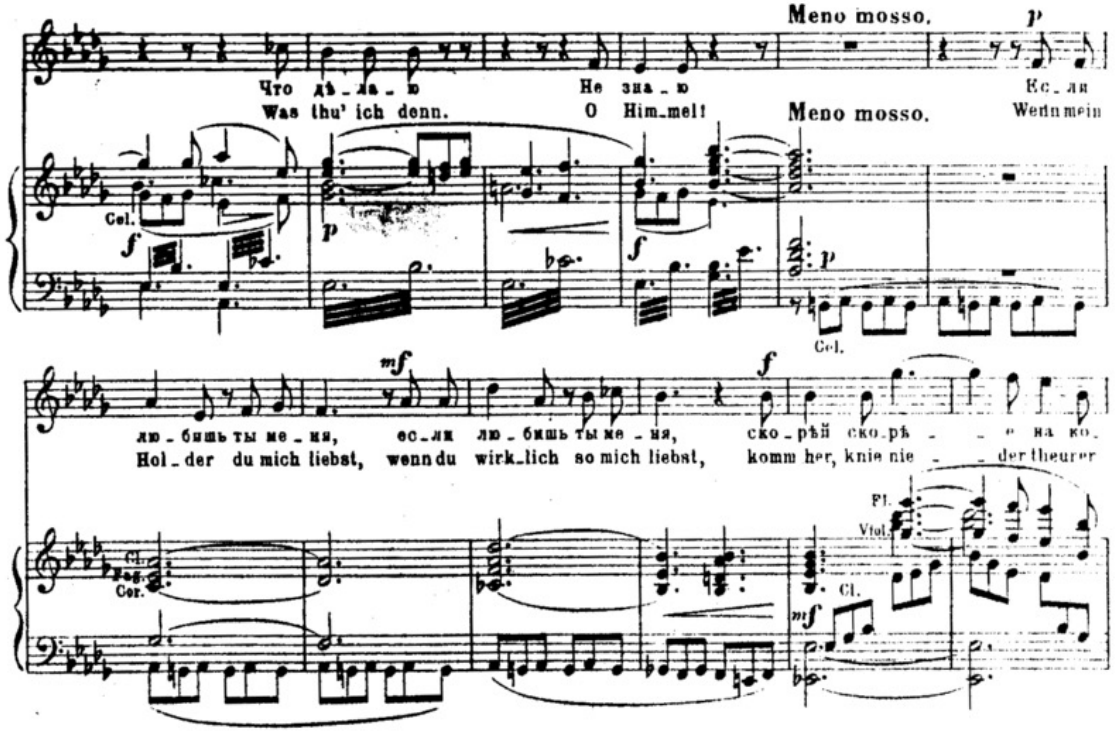
Music (theory) Background



Representing Music



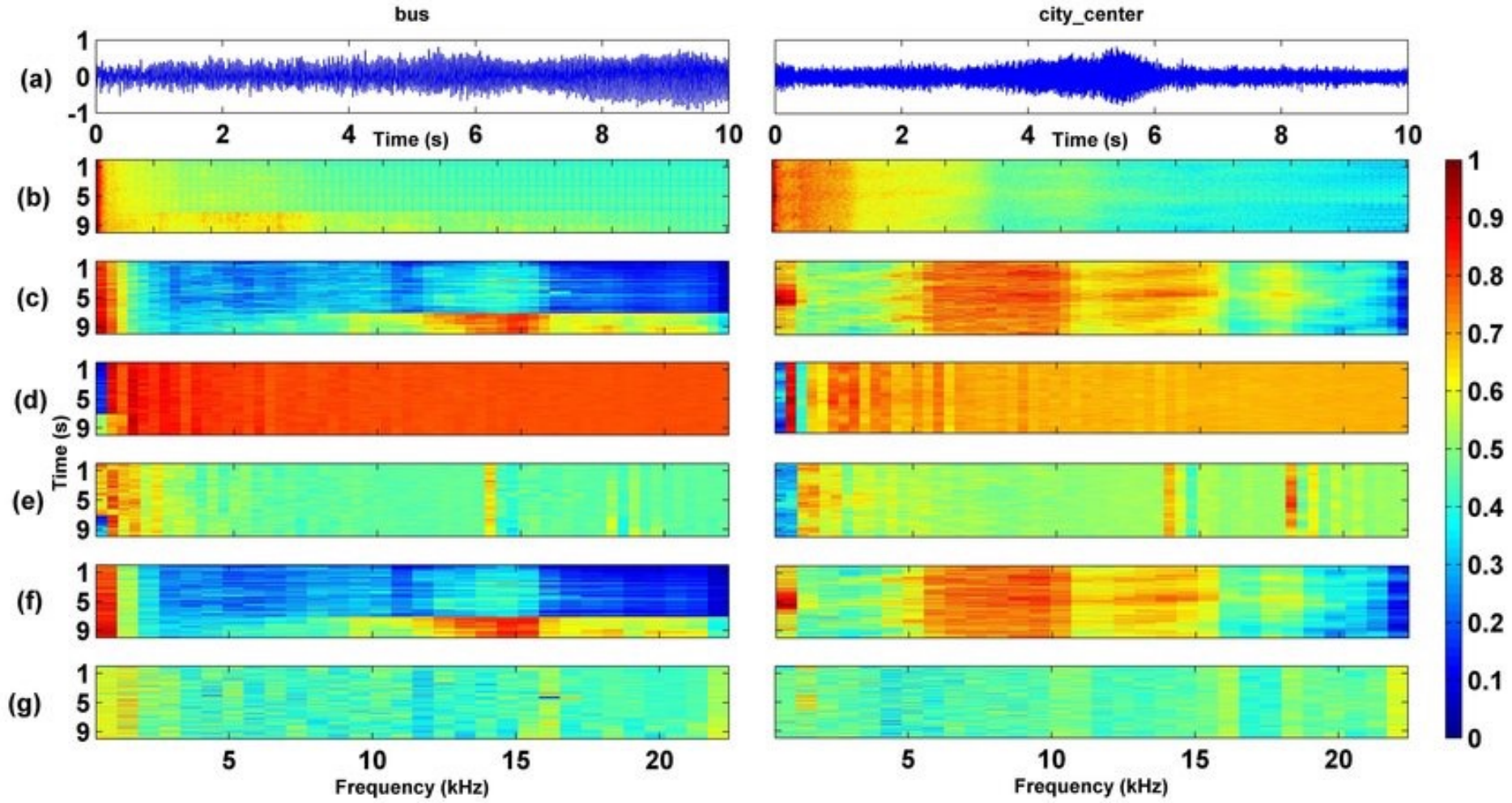
Audio Signal



Symbolic Representation

Audio Signal

- Low structural generality
- High expressive completeness



Symbolic Representations

- High structural generality
- Low expressive completeness (e.g. timbre information usually overlooked)

```
<note>
  <pitch>
    <step>E</step>
    <alter>-1</alter>
    <octave>4</octave>
  </pitch>
  <duration>2</duration>
  <type>half</type>
</note>
```

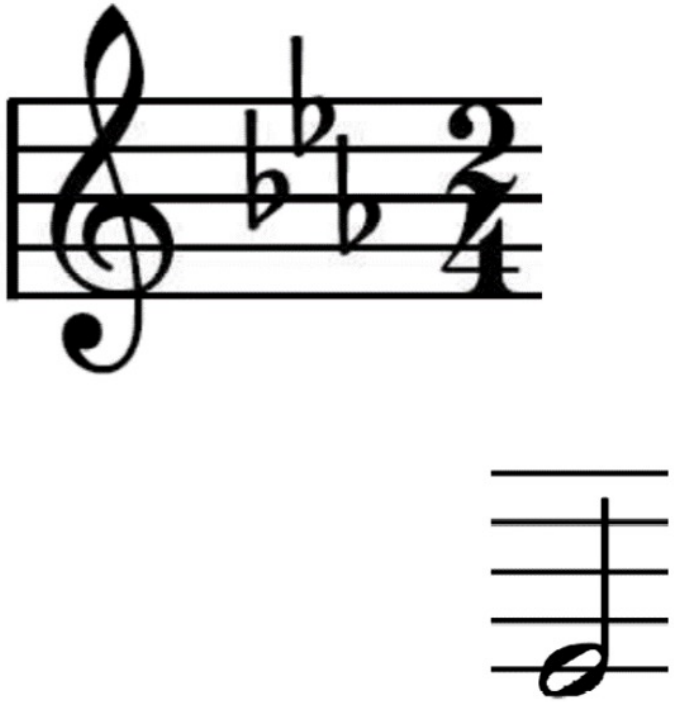


Figure 1.15 from [Müller, FMP, Springer 2015]

Music Similarity

Music similarity is a defined as the ability to measure the similarity between music tracks

Central task in **Music Information Retrieval**

Central in **many fields**:
- Classification
- Recommendation
- Search

Crucial for **Musicology**

Music Similarity

Music similarity can be approached from two different perspectives:

Context-based Similarity

Non-musical data:

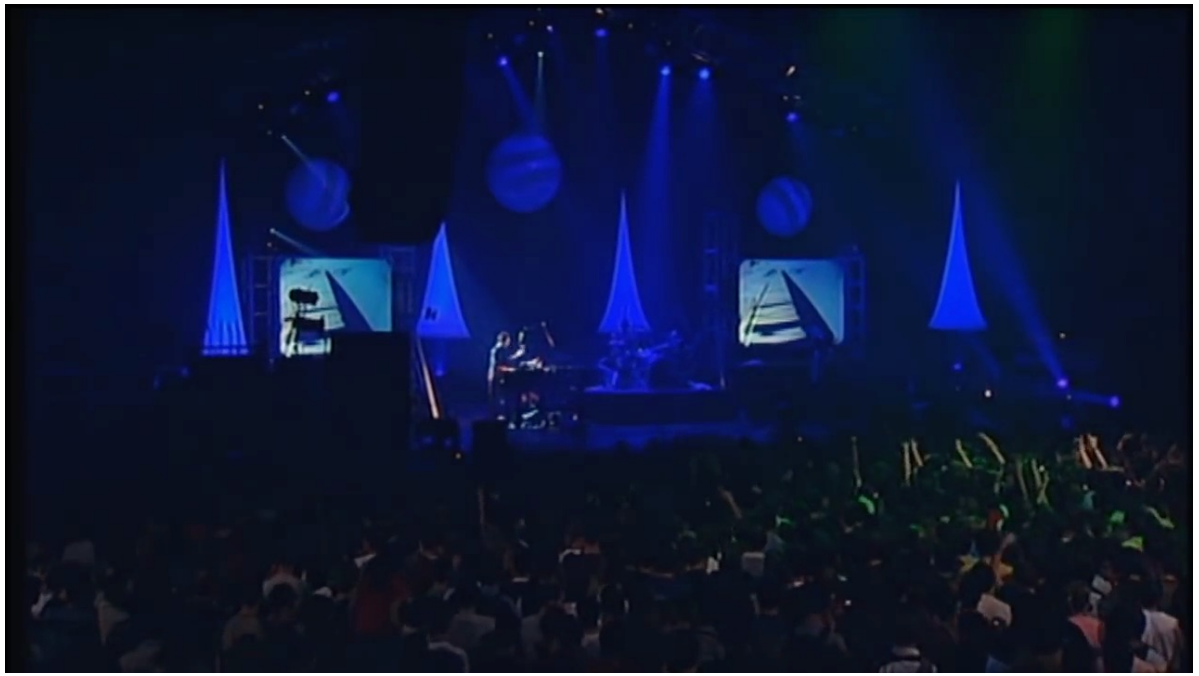
- Metadata
- Song popularity
- Listener's preferences

Content-based Similarity

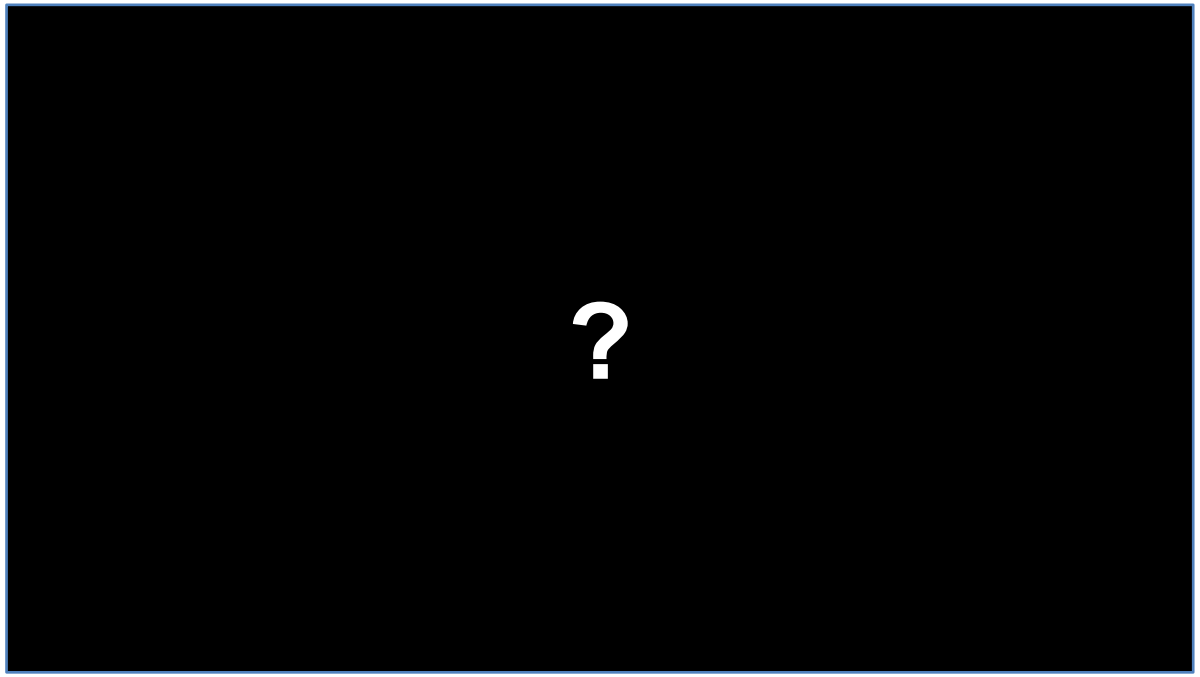
Musical data

Muse - Space Dementia

Can you hear any **similarity** between the two compositions?



Muse – *Space Dementia* (2001)



Rachmaninoff – *Piano Concerto no. 2* (1901)

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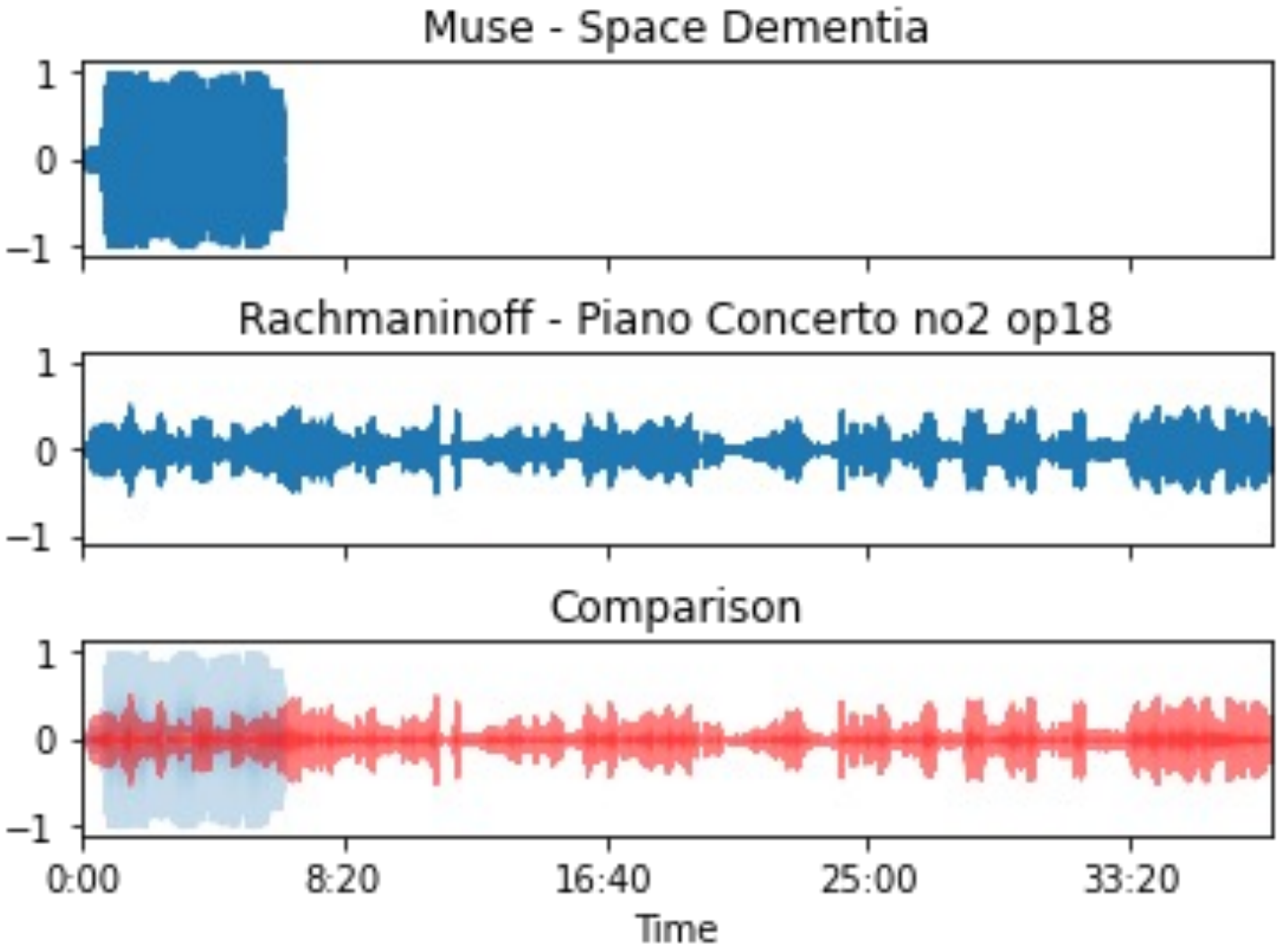
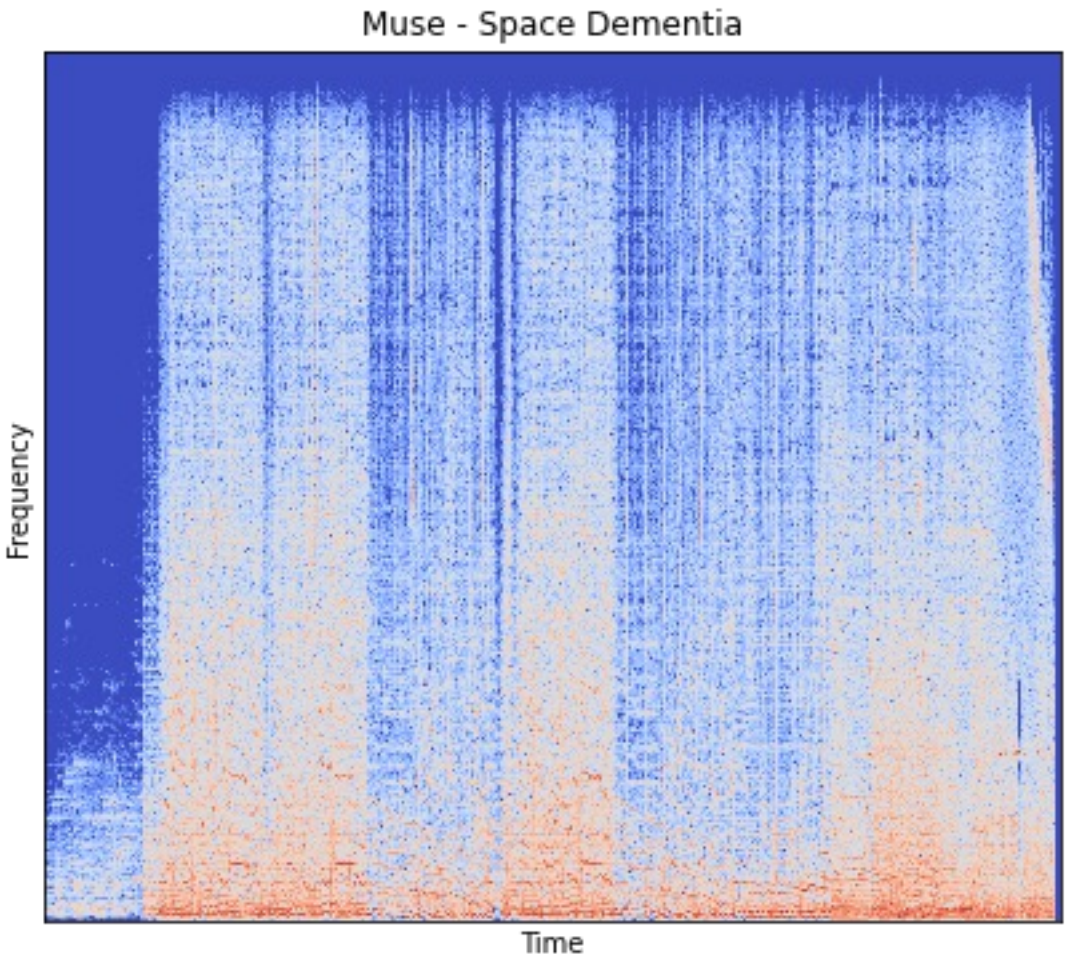
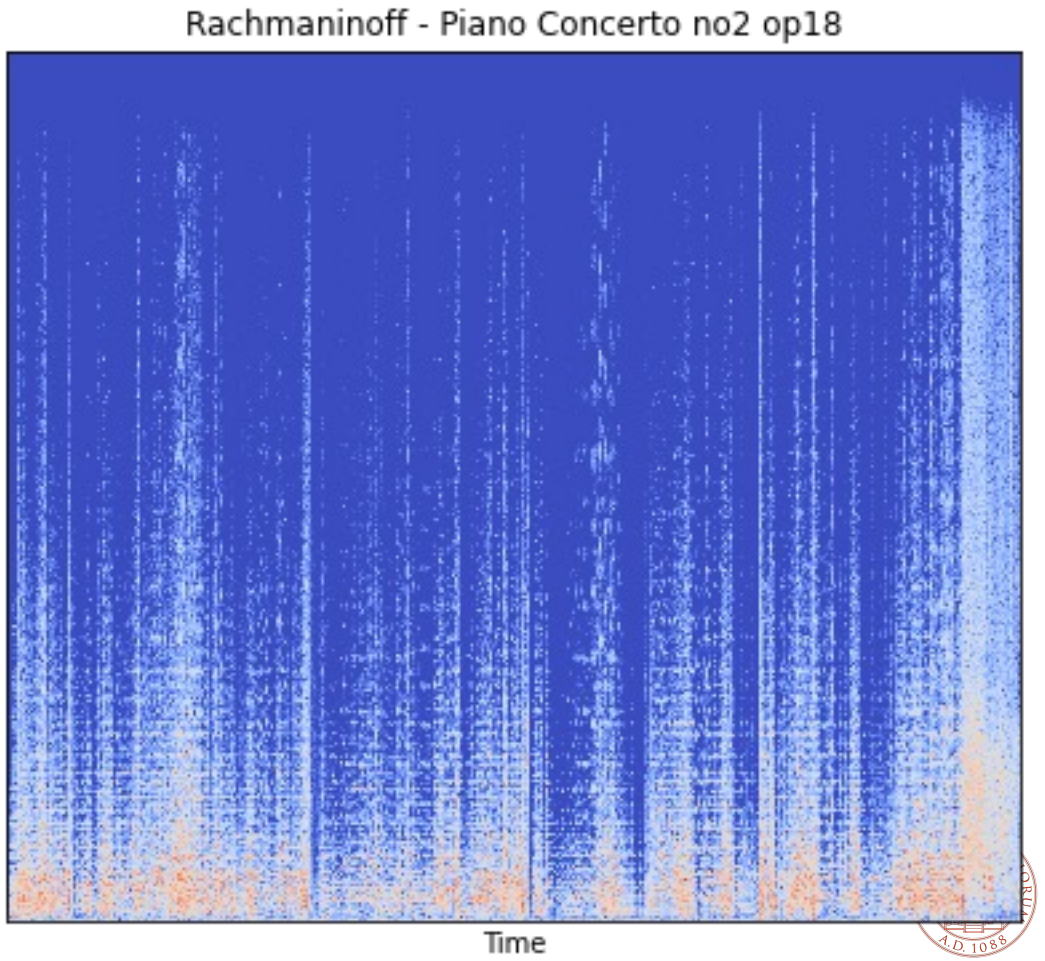
Audio signal analysis is not enough

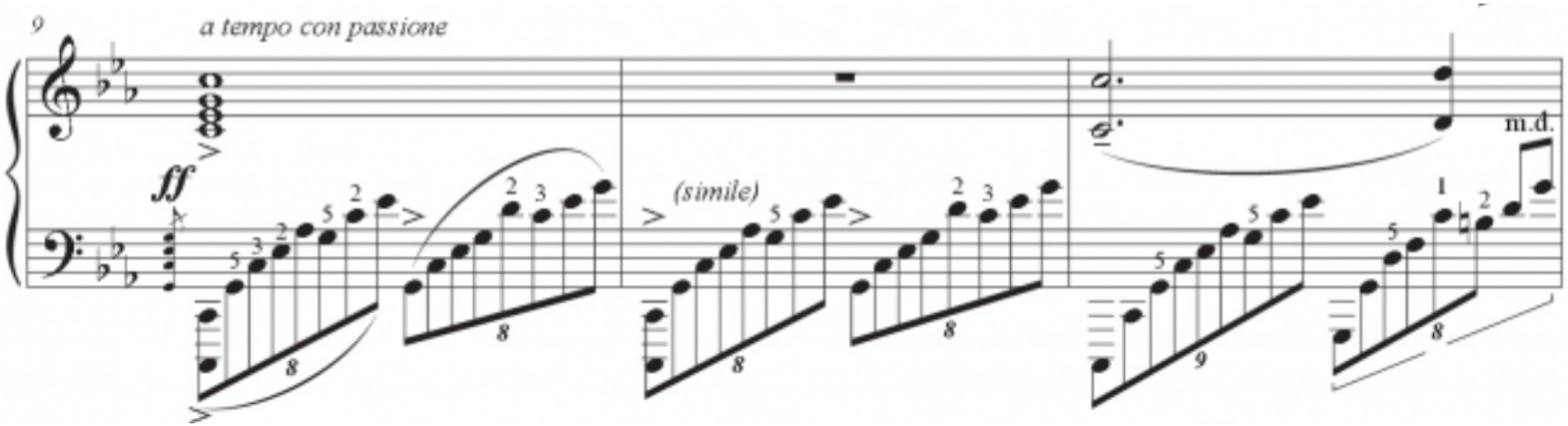


Audio signal analysis is not enough (2)

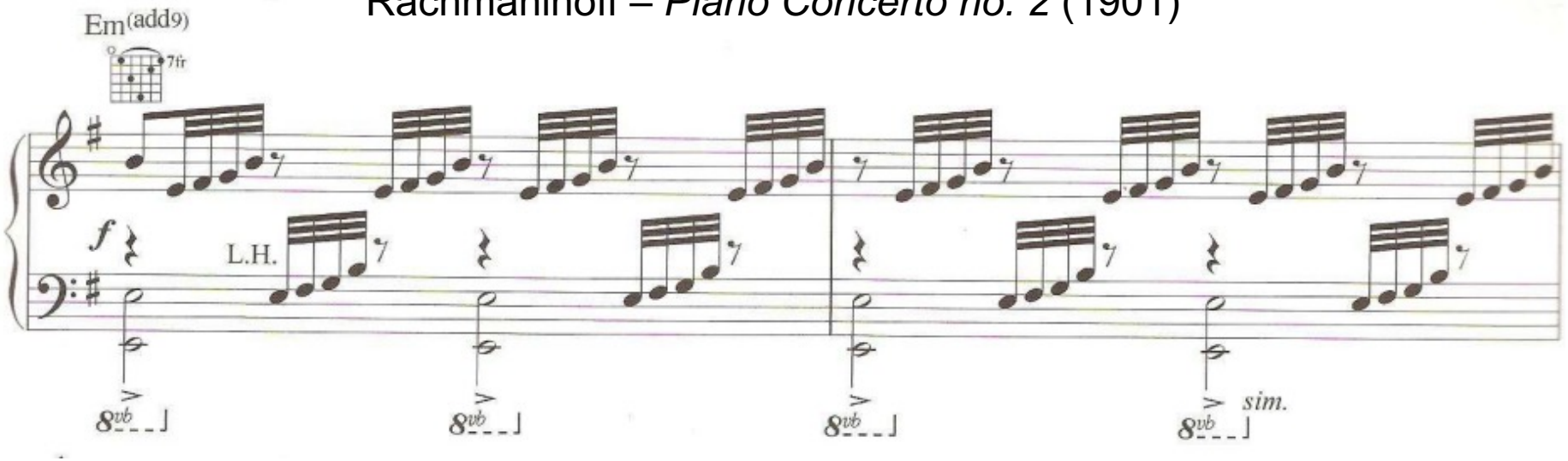




Symbolic similarity



Rachmaninoff – *Piano Concerto no. 2* (1901)

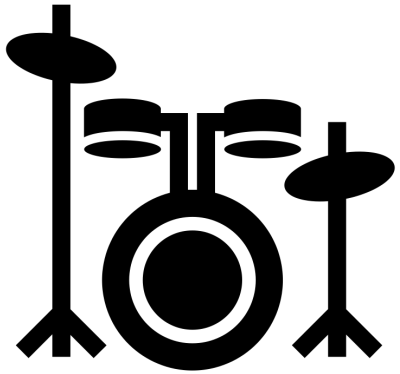


Muse – *Space Dementia* (2001)

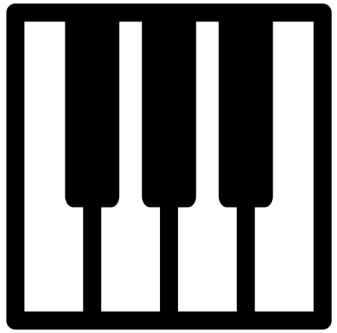
- Same pattern
- Different key
- Different tempo

What is a music composition?

A musical composition is composed by three main elements:



Rhythm



Harmony

Melody

Jean-Benjamin de La Borde

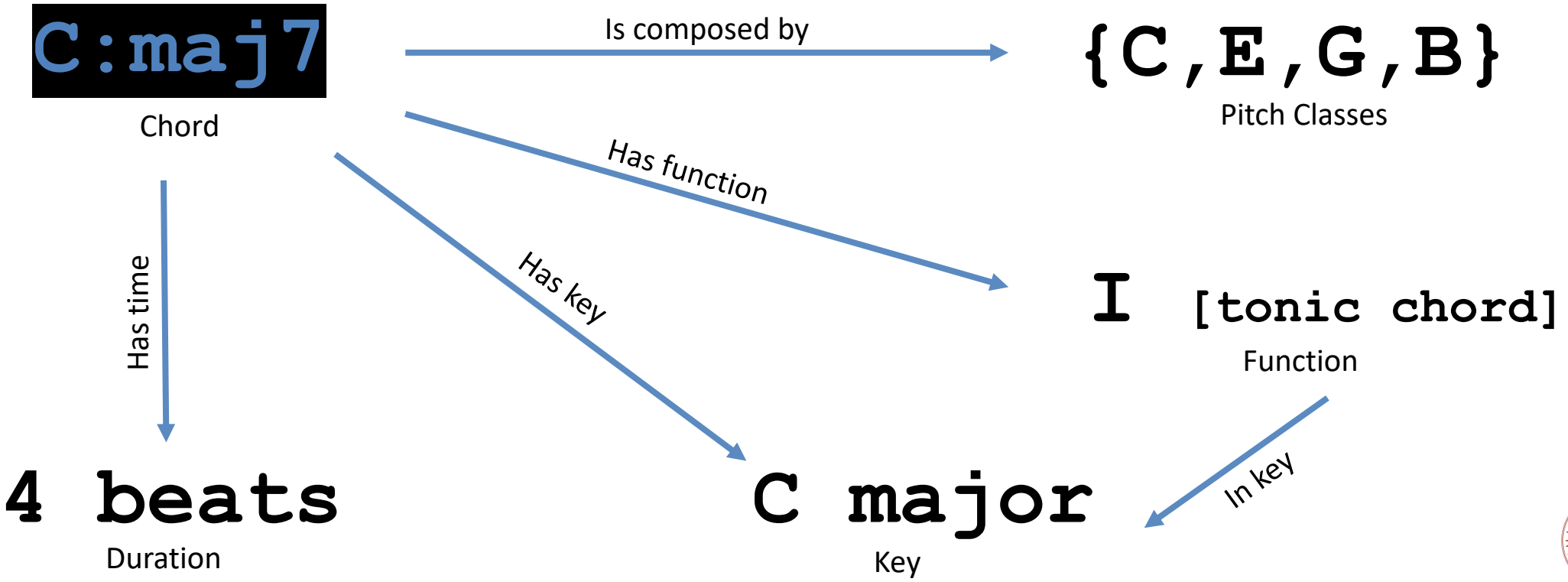
Composition consists in two things only.
The first is [...] what the Ancients called melody.
The second is [...] what we call **harmony** and **it alone merits the name of composition.**

*1780**

What is harmony?

In music, harmony is the process by which individual sounds are joined or composed into whole units or compositions.

Harmony is usually represented through chords.



Today's topics

Today we are going to expore some ideas on how to use **Semantic Web Technologies** can be used for:

1. **Representing musical data** (harmonic data, melodic data, annotations, metadata, etc.)
2. Describing music **similarity**
3. Enhancing **machine creativity**.

02

MUSIC ONTOLOGIES

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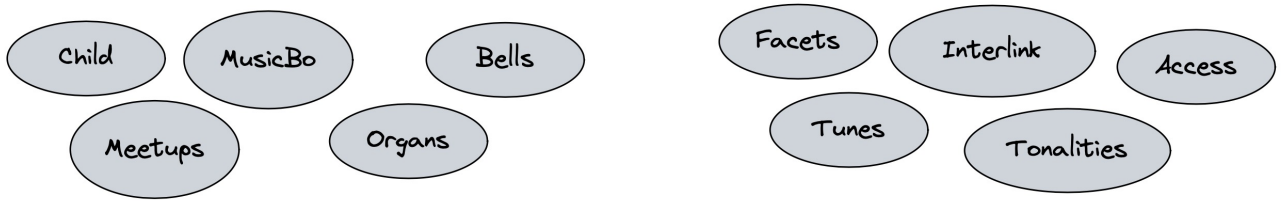
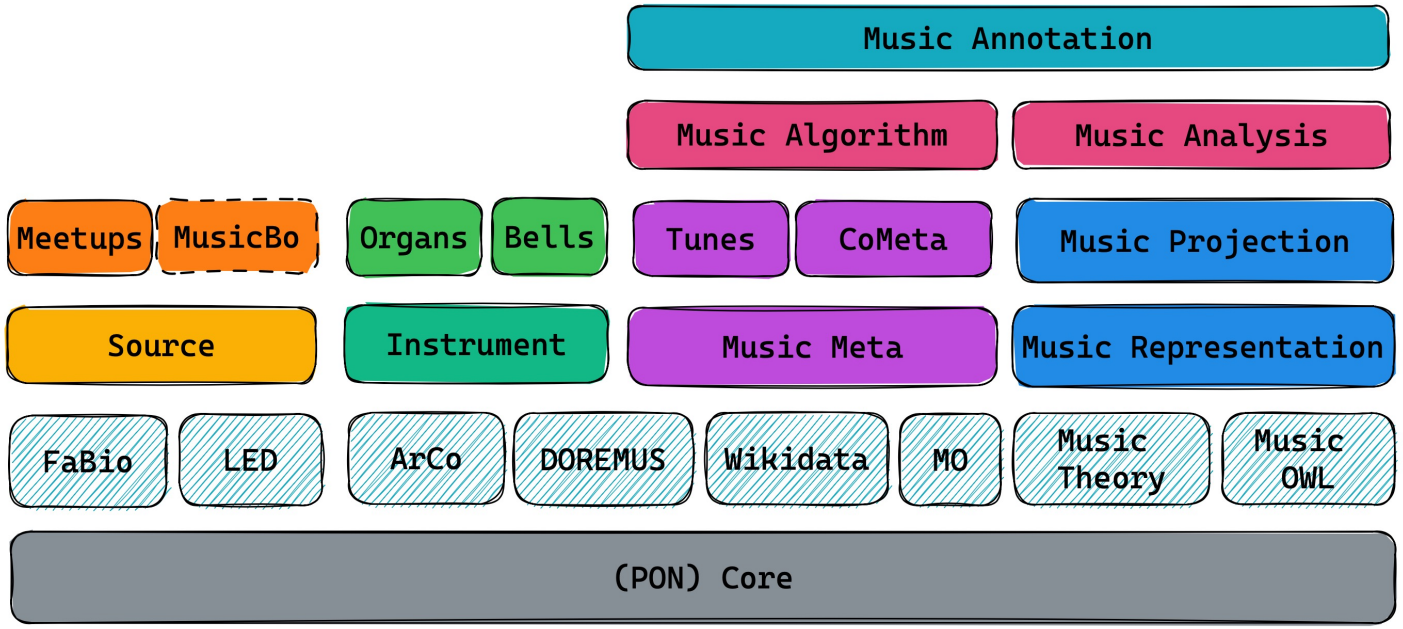
Overview of exsisting Music Ontologies

The Polifonia Ontology Network (PON)

PON is a network of ontologies that can be used for describing heterogenous information in the **music domain**





https://github.com/polifonia-project/ontology-network

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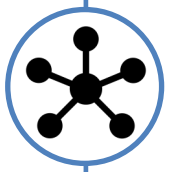
03

CASE STUDIES

Case Studies

I will be introducing two different (yet related) projects which show an **interaction between music and the Semantic Web**:



ChoCo: The Chord Corpus

Harmory: The Harmonic Memory

Terminology (in this presentation)




Chord annotation: the output of a human expert (or a computational method) identifying chords in a piece.
(synonyms here: a sequence of chords / a chord progression)

Chord observation / **occurrence**: the atomic elements of a chord annotation – the individual chords.

Tonality: given by the key (e.g. C) and the scale (e.g. “maj”).

ChoCo in a nutshell

FROM

18 datasets

14 formats

9 notations

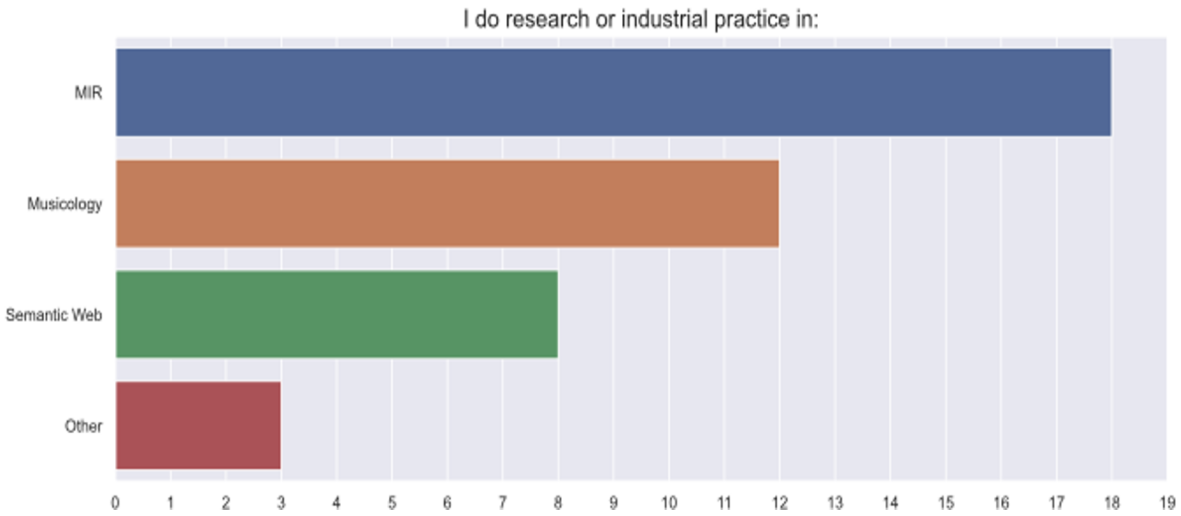
TO

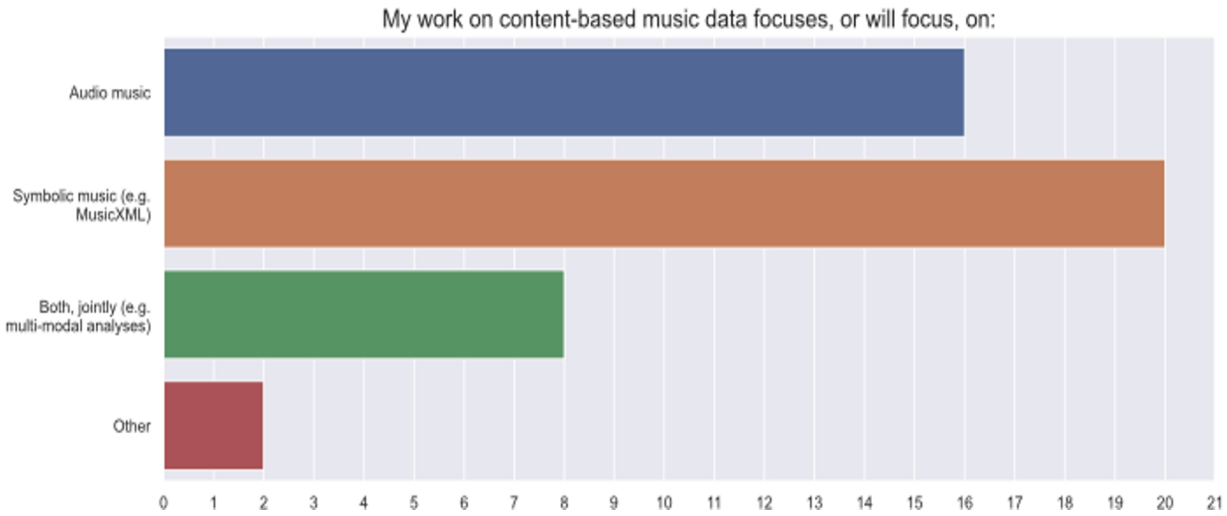
1 dataset

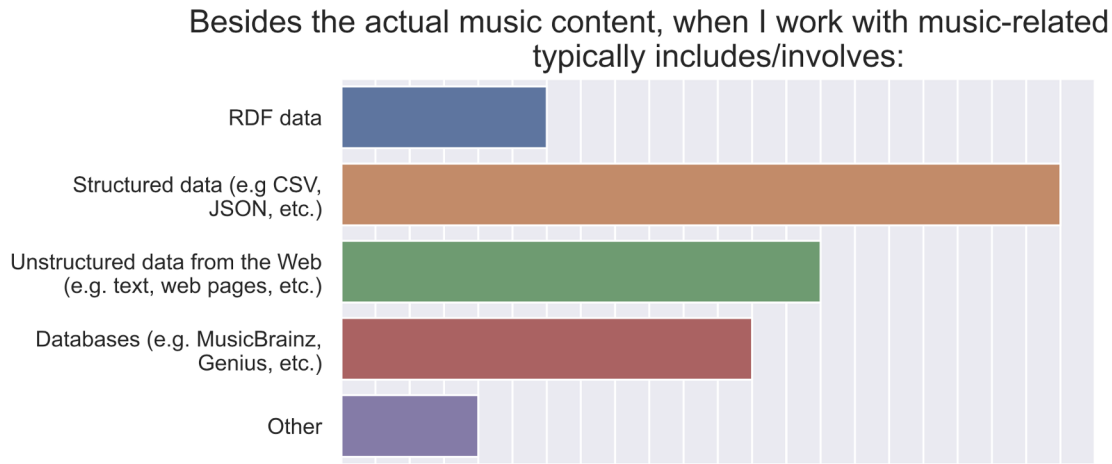
2 outputs

2 notations

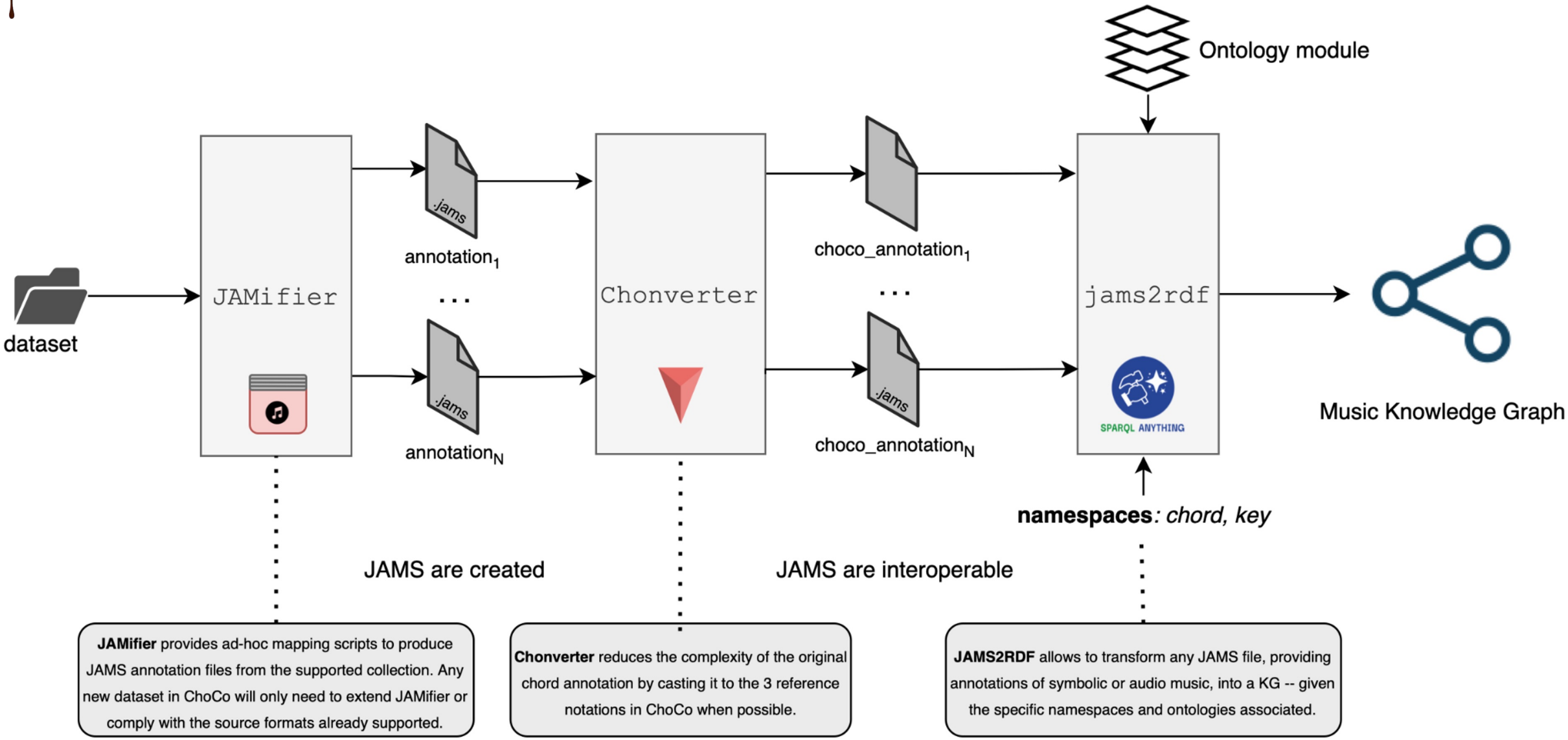
The need for ChoCo







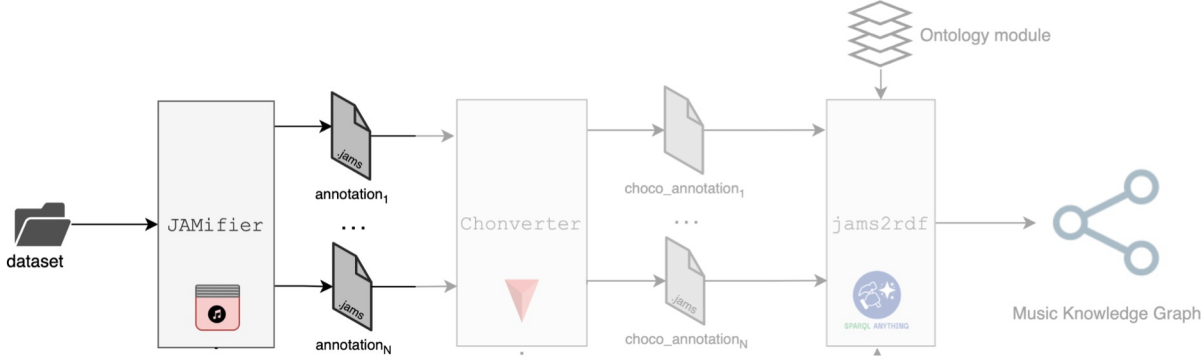
Data transformation workflow

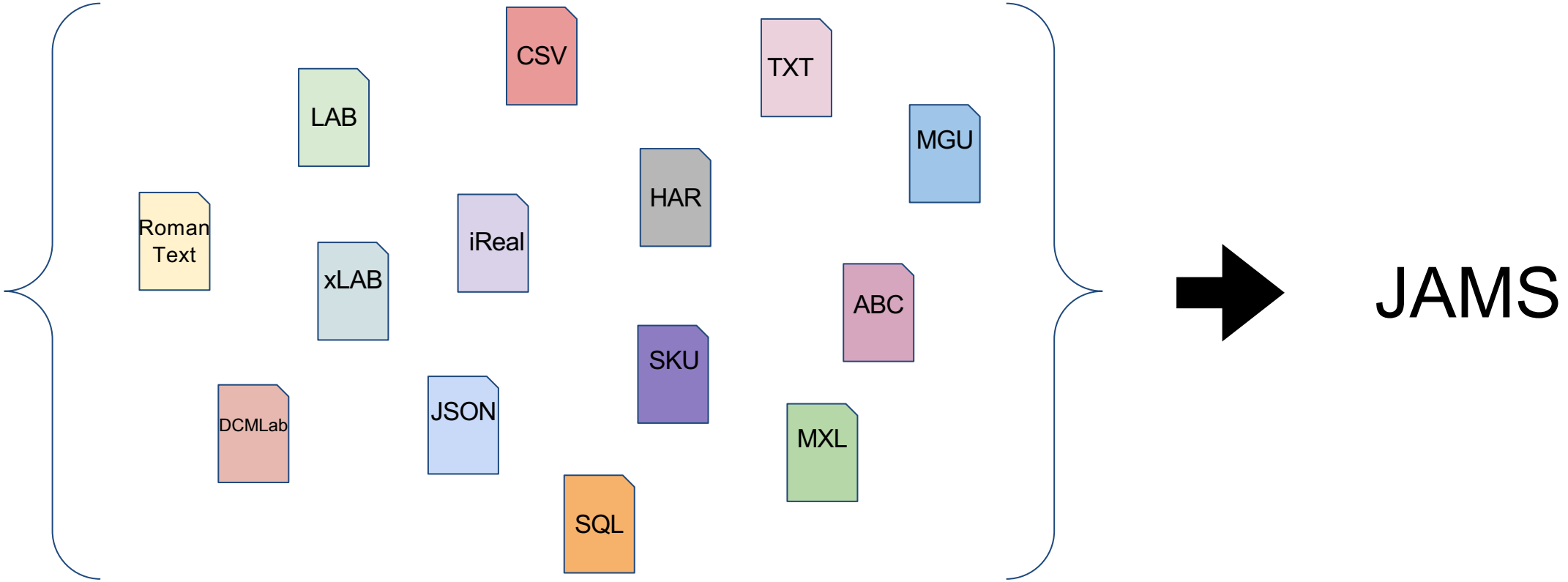


ChoCo

1. Jamifier

Challenge 1: little or no use of **annotation standards**

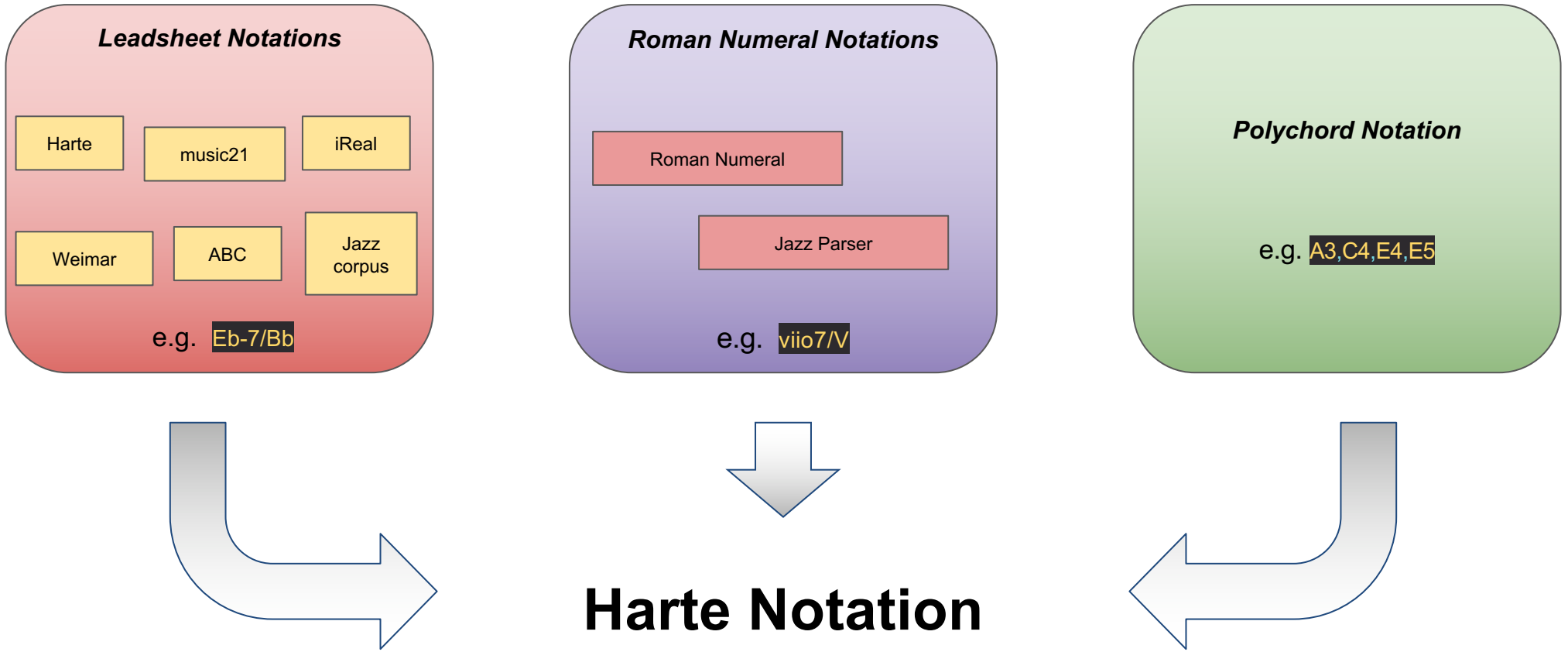




ChoCo

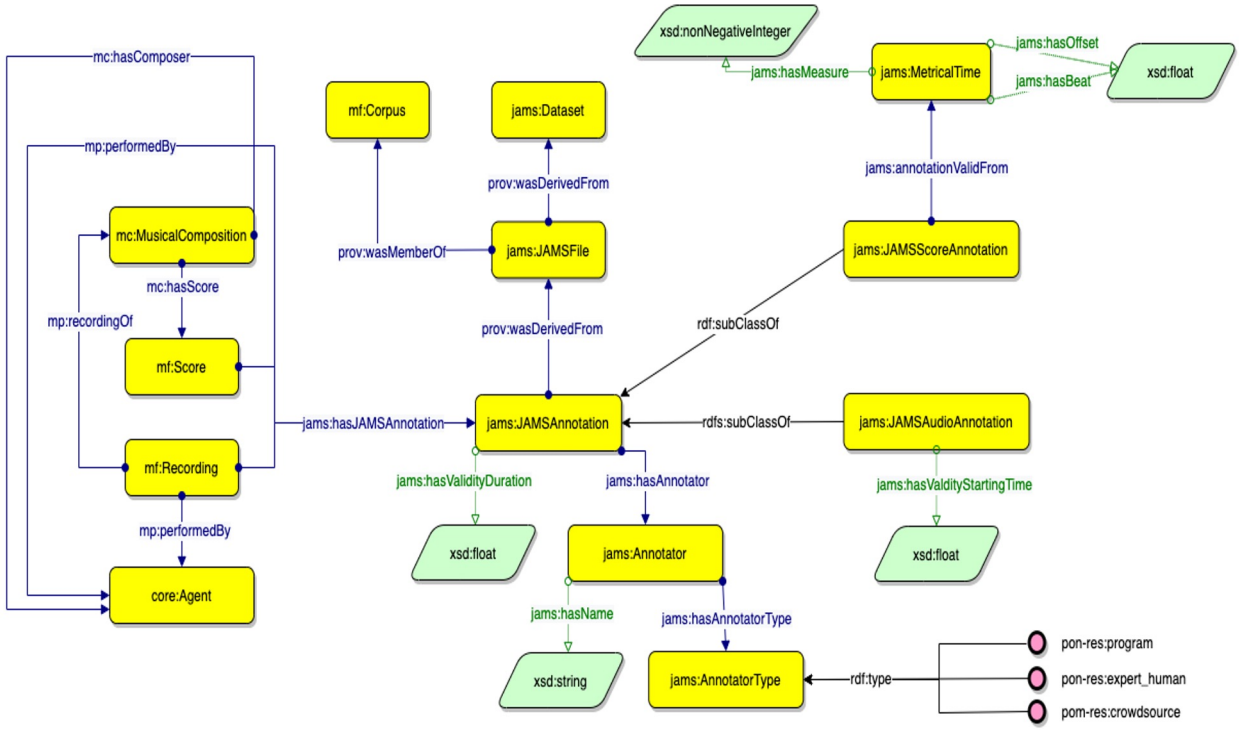
2. Chonverter

Challenge 2: too many **chord notations**



3. KG Generation

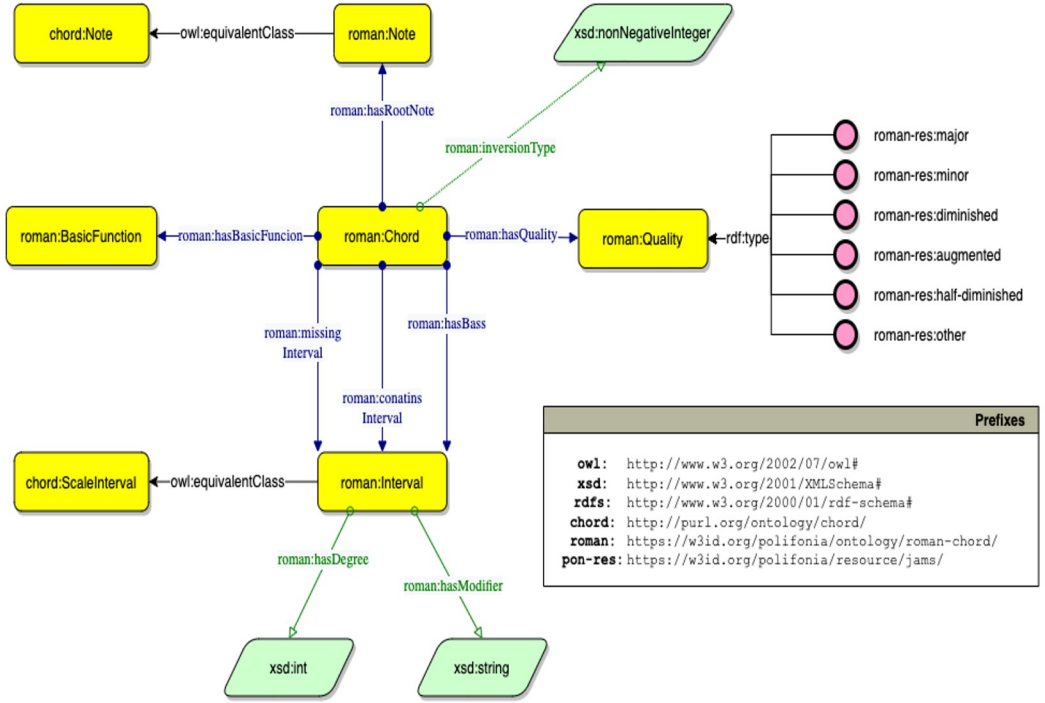
Challenge 3: making ChoCo data available and interoperable



Prefixes

core:	https://w3id.org/polifonia/ontology/core/
jams:	https://w3id.org/polifonia/ontology/jams/
mc:	https://w3id.org/polifonia/ontology/musical-composition/
mp:	https://w3id.org/polifonia/ontology/musical-performance/
mf:	https://w3id.org/polifonia/ontology/musical-feature/
chord:	http://purl.org/ontology/chord/
roman:	https://w3id.org/polifonia/ontology/roman-chord/

Excerpt of the JAMS Ontology



Prefixes

owl:	http://www.w3.org/2002/07/owl#
xsd:	http://www.w3.org/2001/XMLSchema#
rdfs:	http://www.w3.org/2000/01/rdf-schema#
chord:	http://purl.org/ontology/chord/
roman:	https://w3id.org/polifonia/ontology/roman-chord/
pon-res:	https://w3id.org/polifonia/resource/jams/

Excerpt of the Roman Chord Ontology

ChoCo

3. KG Generation

```
CONSTRUCT {
    # the file from which the data is extracted
    ?jams_file_uri a jams:JAMSFile ;
        jams:jamsVersion ?jams_version ;
        jams:release ?release ;
        prov:wasDerivedFrom ?corpus ;
        prov:wasMemberOf <https://github.com/jonnybluesman/choco> .

    # COMPOSITION
    ?composition_uri a mc:MusicalComposition ;
        rdfs:label ?title ;
        mc:title ?title ;
        prov:wasDerivedFrom ?jams_file_uri ;
        # only if the sandbox.type = score
        ?composer_type_relation ?composer_uri .

    # ARTIST COMPOSER
    ?composer_uri ?composer_is_type core:Agent ;
        rdfs:label ?composer .

    # ARTIST PERFORMER
    ?performer_uri ?performer_is_type core:Agent ;
        rdfs:label ?performer .

    # RECORDING
    ?recording_uri ?recording_is_type mp:Recording ;
        ?recording_title ?title ;
        ?recording_label ?title ;
        ?is_recording_of ?composition_uri ;
        ?recording_duration ?duration ;
        ?recording_contained_in ?release ;
        # only if the sandbox.type = audio
```

```
WHERE {
    SERVICE <x-sparql-anything:> {

    fx:properties fx:location ?_filepath ;
        fx:media-type  "application/json" ;
        fx:blank-nodes true .

    ###############
    # SANDBOX
    ###############
    ?x xyz:sandbox ?sandbox .
    ?sandbox xyz:type ?object_type .
    OPTIONAL {?sandbox xyz:performers ?performer_list .
    ?performer_list fx:anySlot ?performer .}
    OPTIONAL {?sandbox xyz:composers ?composer_list .
    ?composer_list fx:anySlot ?composer.}

    OPTIONAL {
        FILTER (?composer != "")
            BIND (mc:hasComposer AS ?composer_type_relation)
            BIND (rdf:type AS ?composer_is_type)
            BIND (rdf:type AS ?score_type)
            BIND (mc:isScoreOf AS ?is_score_of)
            BIND (rdfs:label AS ?score_label)
            BIND (mf:duration AS ?score_duration)
    }
    OPTIONAL {
        FILTER (?performer != "")
            BIND (mp:performedBy AS ?performer_type_relation)
            BIND (rdf:type AS ?performer_is_type)
    }
```

ChoCo Overview of ChoCo's content

Partition	Type	Notation	Original format	Annotations	Genres	Ref
Isophonics	A	Harte	JAMS	300	pop, rock	19
JAAH	A	Harte	JSON	113	jazz	20
Schubert-Winterreise	A, S	Harte	csv	25 (S), 25*9 (A)	classical	21
Billboard	A	Harte	LAB, txt	890 (740)	pop	22
Chordify	A	Harte	JAMS	50*4	pop	6
Robbie Williams	A	Harte	LAB, txt	61	pop	23
The Real Book	S	Harte	LAB	2486	jazz	24
Uspop 2002	A	Harte	LAB	195	pop	25
RWC-Pop	A	Harte	LAB	100	pop	26
Weimar Jazz Database	S	Leadsheet	SQL	456	jazz	27
Wikifonia	S	Leadsheet	mxl	6500+	various	-
iReal Pro	S	Leadsheet	iReal	2000+	various	-
Band-in-a-Box	S	Leadsheet	mgu, sku	5000+	various	28
When in Rome	S	Roman	RomanText	450	classical	29
Rock Corpus	S	Roman	har	200	rock	30
Mozart Piano Sonata	S	Roman	DCMLab	54 (18)	classical	4
Jazz Corpus	S	Hybrid	txt	76	jazz	31
Nottingham	S	ABC	ABC	1000+	folk	32

20K+ JAMS files

with 42K+ different annotations

~21K chord annotations (Harte)

20K+ of tonality and modulations.

554 structural annotations

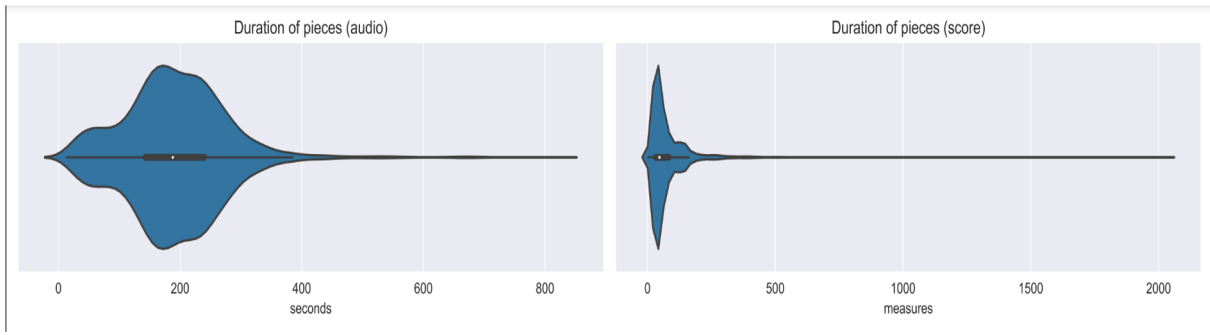
286 beat annotations

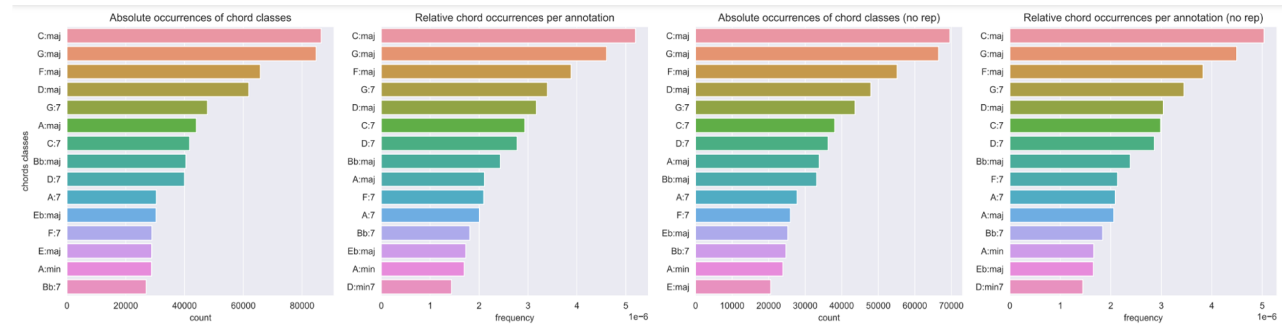
711 unique external identifiers

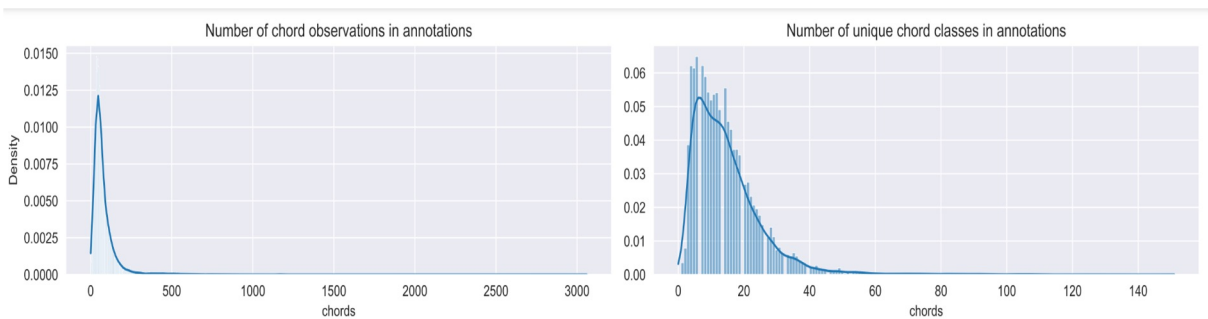
1,642,625 chord occurrences

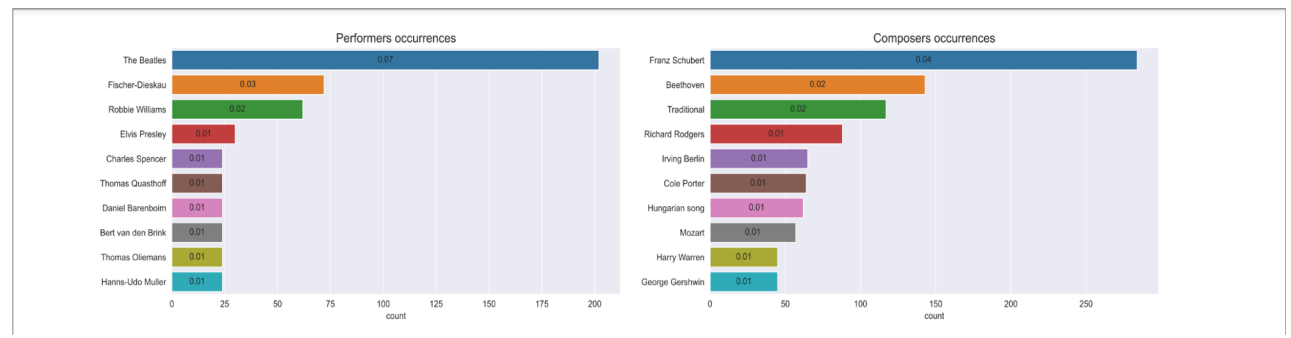
7,281 possible chord classes (Harte).

ChoCo


Duration of pieces (audio)
0
200
400
600
800
seconds
Duration of pieces (score)
0
500
1000
1500
2000
measures


Absolute occurrences of chord classes
Relative chord occurrences per annotation
Absolute occurrences of chord classes (no rep)
Relative chord occurrences per annotation (no rep)
chords classes
C:maj
G:maj
F:maj
D:maj
G:7
A:maj
C:7
Bb:maj
D:7
A:7
Eb:maj
F:7
E:maj
A:min
Bb:7
D:min7
count
frequency
1e−6


Number of chord observations in annotations
Density
chords
Number of unique chord classes in annotations
chords


Performers occurrences
The Beatles
Fischer-Dieskau
Robbie Williams
Elvis Presley
Charles Spencer
Thomas Quasthoff
Daniel Barenboim
Bert van den Brink
Thomas Oliemans
Hanns-Udo Muller
count
Composers occurrences
Franz Schubert
Beethoven
Traditional
Richard Rodgers
Irving Berlin
Cole Porter
Hungarian song
Mozart
Harry Warren
George Gershwin
count

Links to external resources

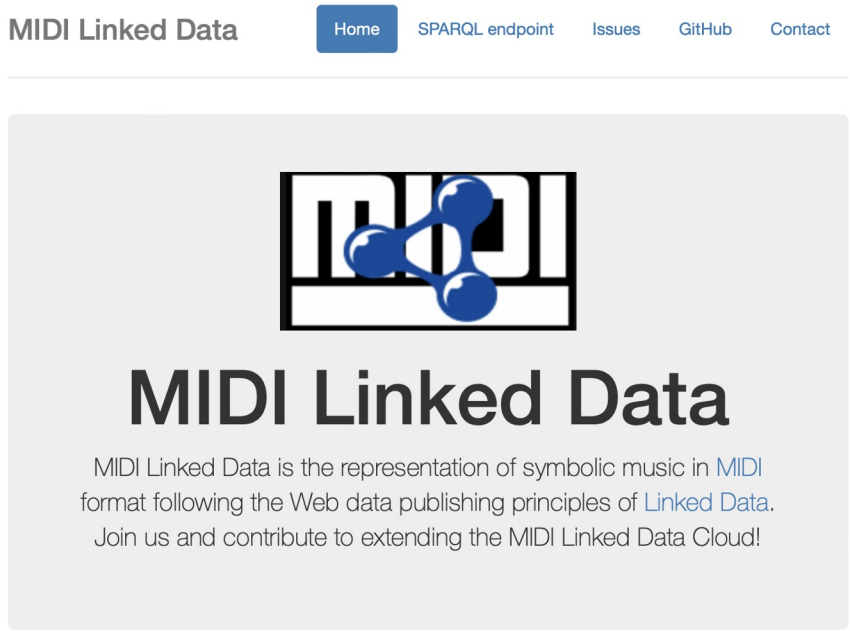
2.4K links to MIDI-LD, ~2K to LED

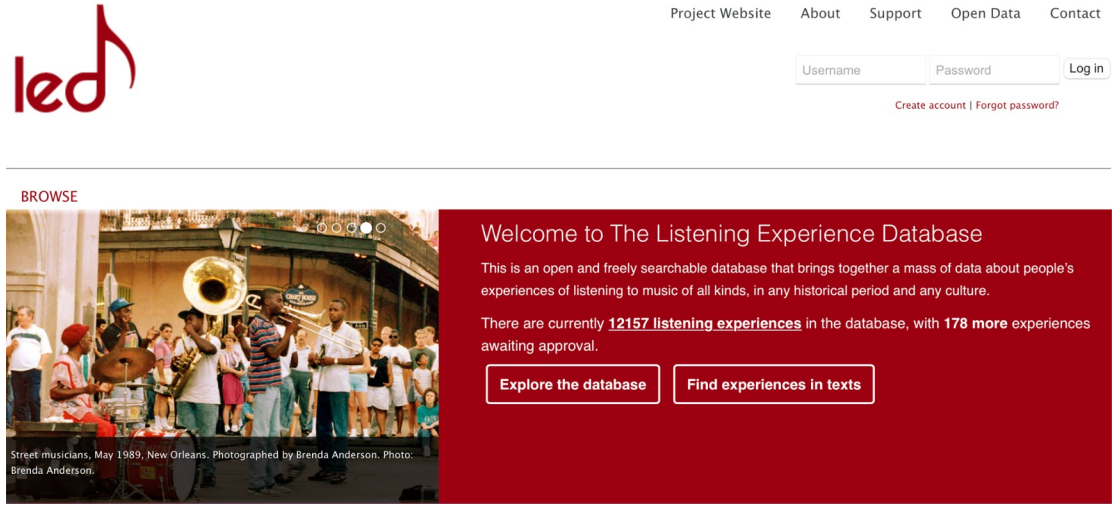
Additional links open up new research directions

Relating harmonic content (chord changes, harmonic complexity, tension, etc.) to other musical properties that are inherently present in the music (melodic contour, expressive variations, instrumental changes, etc.), or that may have been elicited certain emotions, memories, and feelings to listeners.

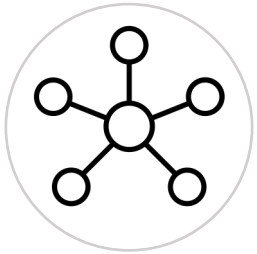
Example of listening experience of the "**So What**" (J. Coltrane) in LED (~/led/lexp/1431335026178)

> *«What do you mean by playing "without harmony"? Using a pedal tone, which Coltrane got into after a period of very dense harmonic playing. He would use one or two harmonic references throughout a song, as he did on "So What" [from Miles Davis's Kind of Blue, on Columbia]. It was basically D for sixteen bars, E flat for eight bars, and then back to D. Ultimately, he worked with only one harmonic reference point, and then in "Ascension" [from Best of John Coltrane: His Greatest Years, on Impulse] there was nothing harmonically.»*
>
> (Steve Kuhn in "The Great Jazz Pianists: Speaking of Their Lives and Music





Harmory in a nutshell



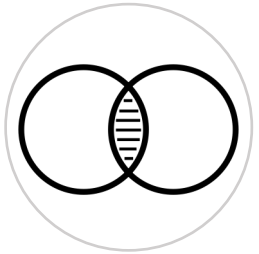
Harmory is a resource

Harmory is Knowledge Graph (KG)

Harmory contains harmonic data

Harmory contains:

1. Segmented harmonic patterns
2. Similarity information



Harmory can be used for AI creativity

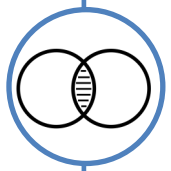
Harmory can be used a trustworthy framework for computational creativity

Harmory: the Harmonic Memory

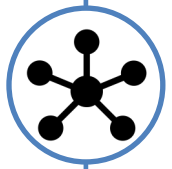
The creation of the Harmonic Memory can be summarised in four main steps

Encoding chords in the **Tonal Pitch Space**

Novelty-based **harmonic segmentation**



Linking harmonic segments via **similarity**



Knowledge Graph creation

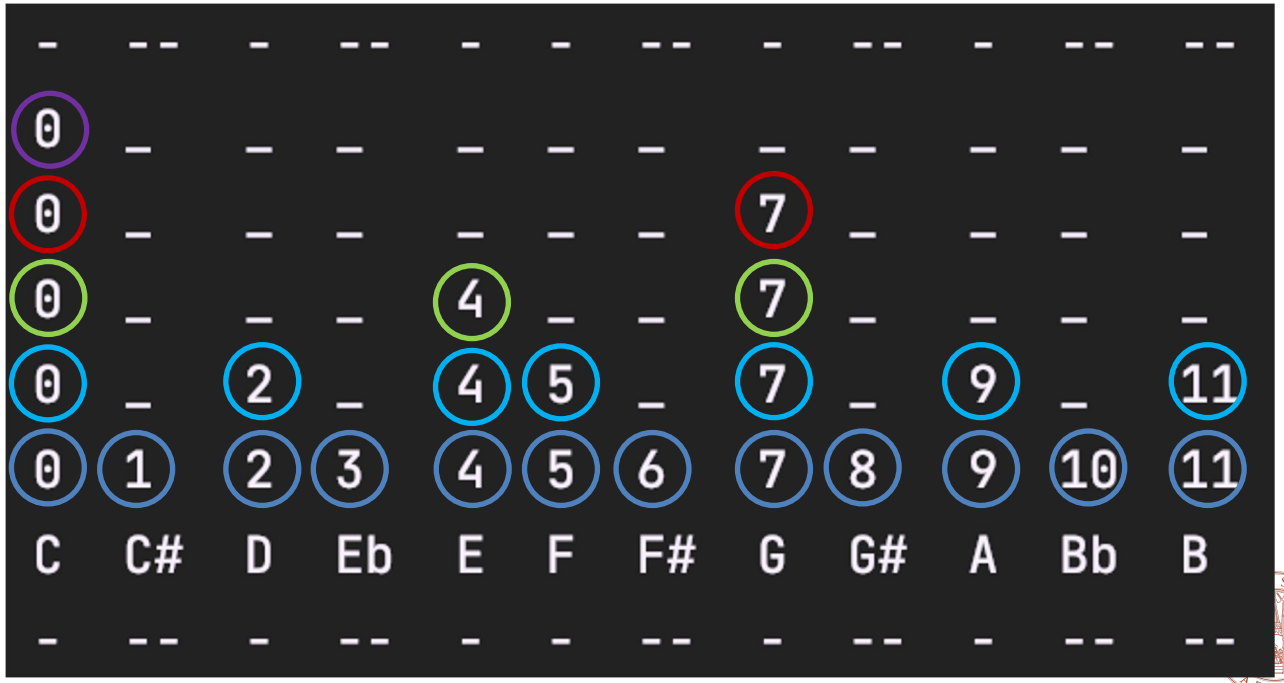
1. Encoding Chords in the Tonal Pitch Space (TPS)

The TPS provides a **scoring mechanism** that predicts the **proximity between two musical chords**.

It is based on the *Generative Theory of Tonal Music* and it is musicologically grounded.

It is composed by **five levels**:

1. Root level
2. Fifths level
3. Triadic level
4. Diatonic level
5. Chromatic level



Example of a C major chord levels of the TPS

1. Encoding Chords in the Tonal Pitch Space (TPS) (2)

The TPS distance between two chords (A and B) is calculated considering:

Difference between a C major and a E major chords according to the TPS

1. Number of **non-common pitch classes** divided by 2 in the levels (i-iv)

+

2. Minimum number of **Circle-of-Fifths rule** applications to shift between chord A and B

1. Encoding Chords in the Tonal Pitch Space (TPS) (3)

For a chord sequence, each chord is encoded as its distance to its local key.

For each comparison between two chords, the TPS returns a value in [0, 13].

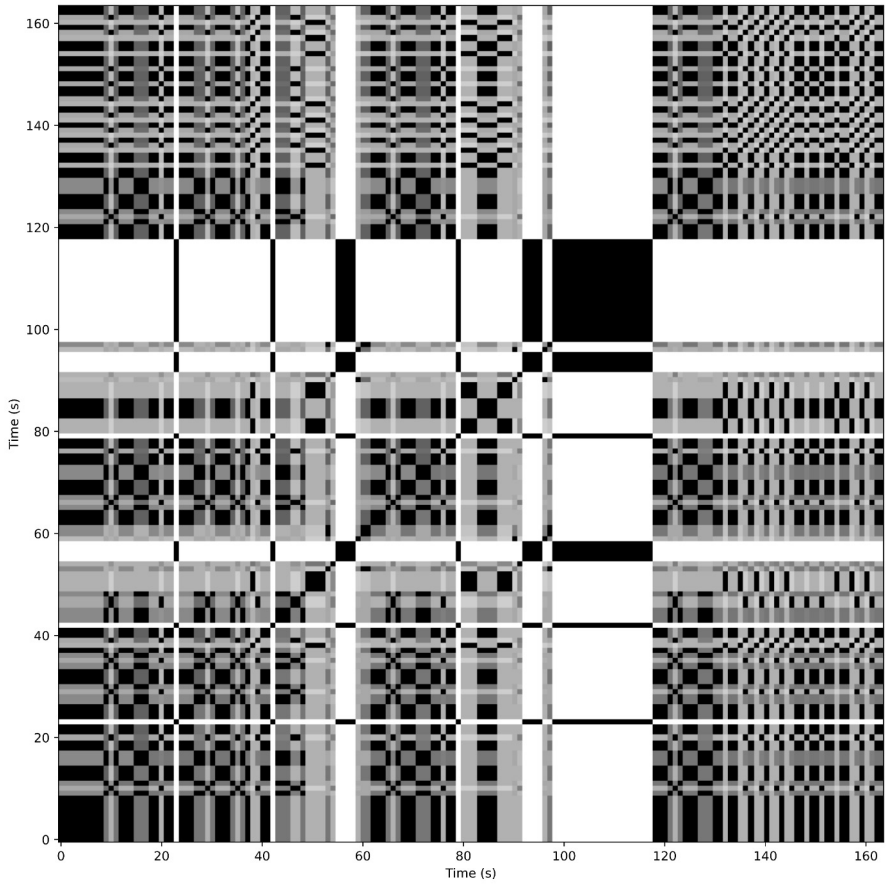
Chord sequence (*c*): [G, B:min, E:min7, . . .]
Tonal keys of c (*k*): [(G, major), (G, major), (G, major), . . .]
Onsets (*t*): [1, 3, 5, . . .]

TPS sequence: [2.0, 3.5, 0.0, 8.9, …]

2. Novelty-based Harmonic Segmentation

- A **Self Similarity Matrix (SSM)** is encoded starting from the TPS sequences

- Self-similarity matrices have been extensively used for **structure analysis on the audio signal**, due to their ability to reveal nested structural elements

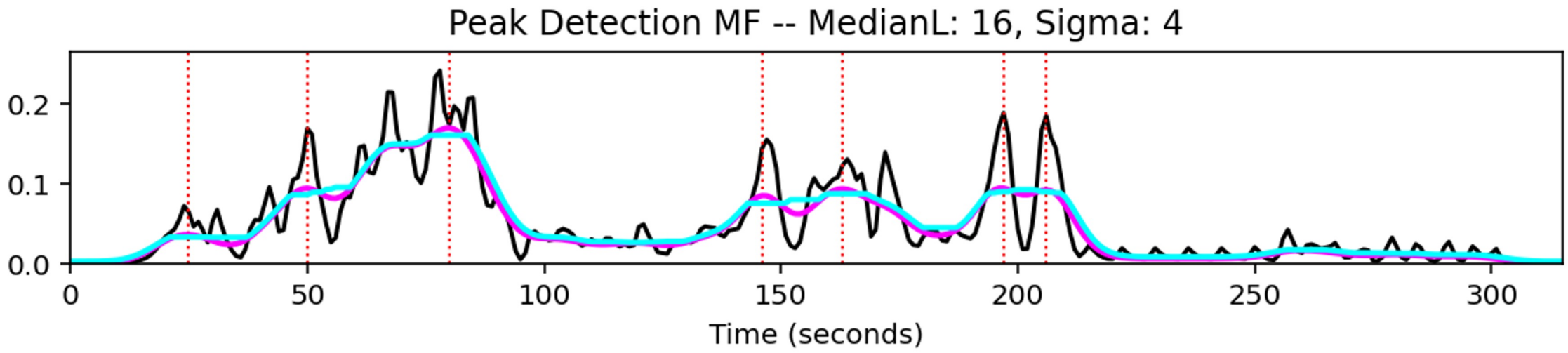


SSM of the track *"Crazy Little Thing called Love"*

2. Novelty-based Harmonic Segmentation (2)

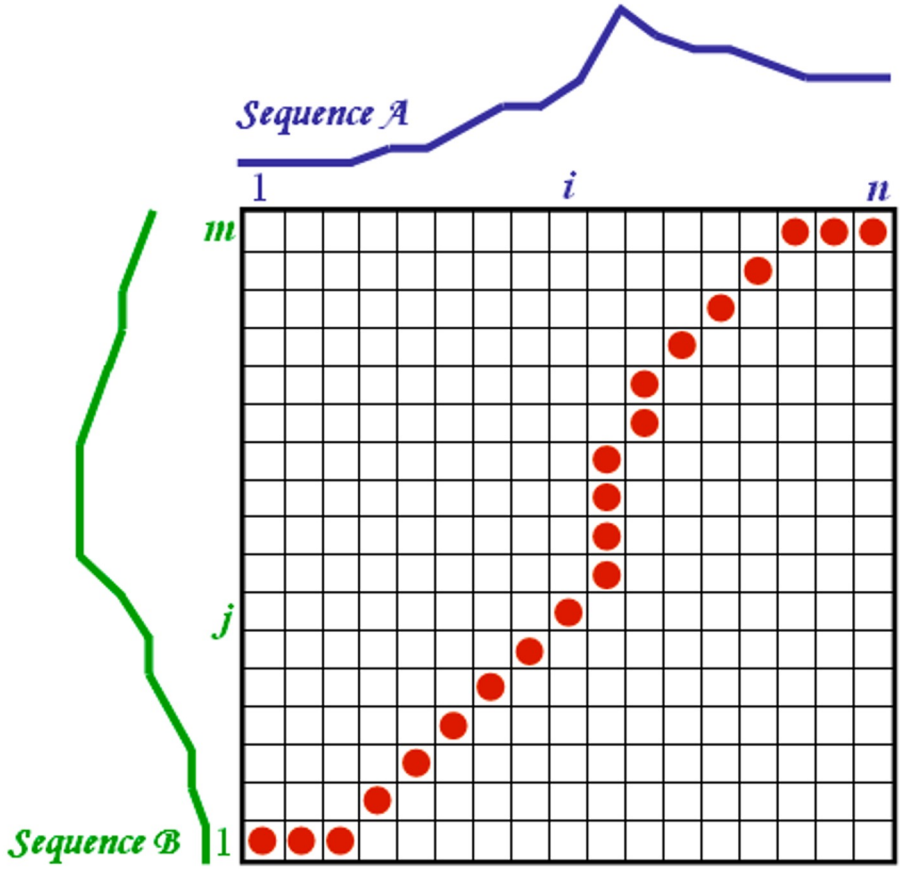
- To identify boundaries a **checkboard kernel (K)** is slided along the SSM main diagonal: this creates a **Novelty Curve:**
  - When K is located in a uniform region, **novelty** will be **low**
  - When K is at the crux of a checkerboard-like structure, **novelty** will be **high**

- Local maxima of the novelty curve are then used to **detect the boundaries** of neighbouring segments



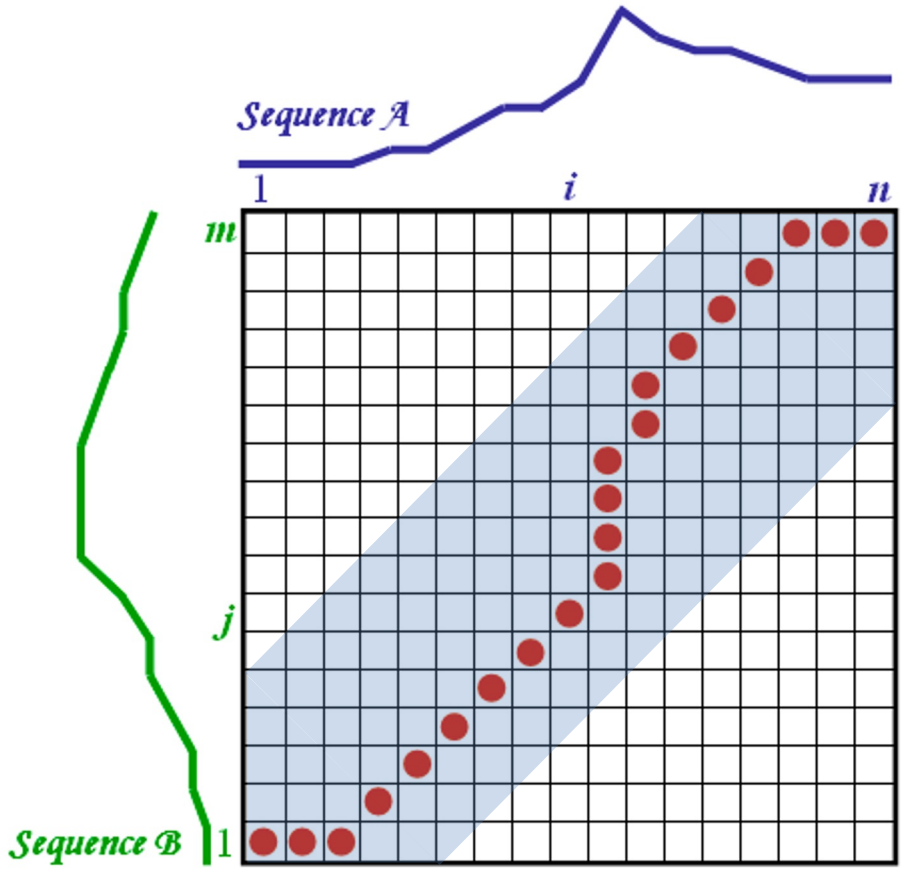
3. Linking Harmonic Segments via Similarity

- The TPS encoded sequences are compared using a **Dynamic Time Warping (DTW) algorithm**
- DTW is used for comparing and aligning time sequences (usually in the audio domain)
- DTW allows for non-linear alignment between the time series by considering the local warping path



3. Linking Harmonic Segments via Similarity (2)

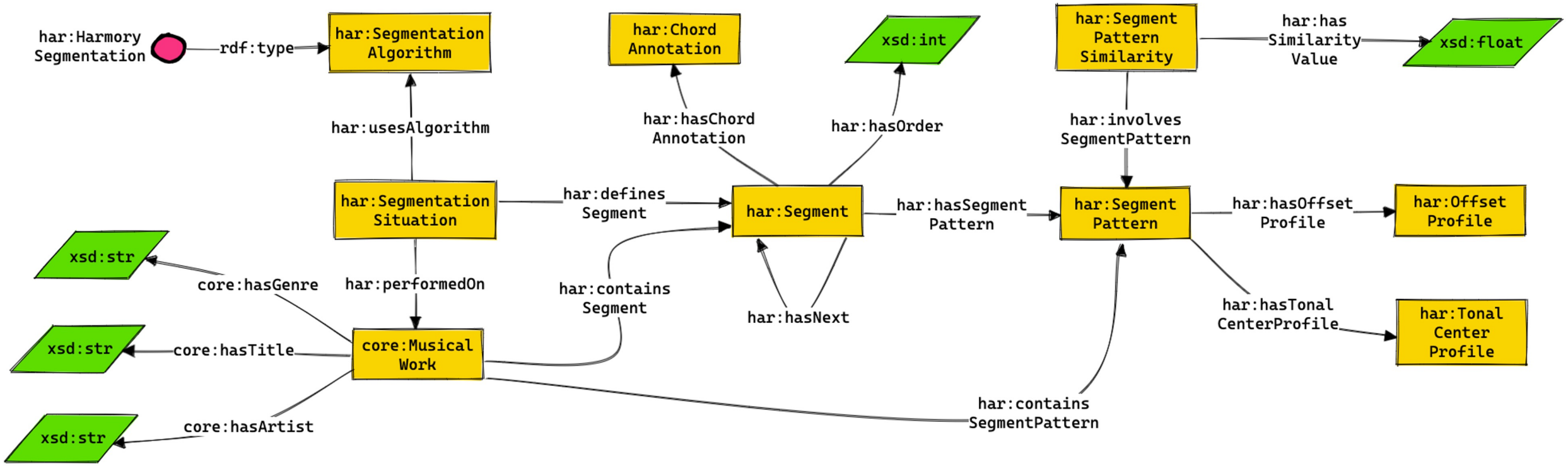
- We used a variant of the vanilla DTW algorithm: **Sakoe-Chiba**
- Sakoe-Chiba allows to **constraint the search space** of the algorithm within a band ***(w)***
- This leads to a drop in computational time complexity:
  - Vanilla DTW: $O(N^2)$
  - Sakoe-Chiba DTW: $O(N * w)$



4. Knowledge Graph Creation

- An **ontology** for describing Harmory data has been created
- The ontology is part of the **Polifonia Ontology Network** (PON)
- Data has been transformed using **RDFLib**
- The generated Knowledge Graph contains **1429070 triples**

4. Knowledge Graph Creation (2)



Prefixes

```
har: http://w3id.org/polifonia/ontology/harmory/
owl: http://www.w3.org/2002/07/owl#
rdfs: http://www.w3.org/2000/01/rdf-schema#
core: https://w3id.org/polifonia/ontology/core/
```

Avenues for Computational Creativity: 1 – Pattern Discovery

The traversal of the Harmonic Memory makes it possible to obtain granular information of the harmonic structure of songs

Prompt 1: *For a given pattern, which are the tracks (titles, artists and genres) in which the pattern can be found?*

Prompt 2: *Which harmonic patterns are used in "Michelle" by The Beatles, but also in a classical composition?*

Prompt 3: *Which tracks include a dominant cycle in seven steps?*

Avenues for Computational Creativity: 2 – Chord Generation

Harmory also enables combinational creativity use cases:

Prompt 4: *Given a chord sequence, which are its variations, and which tracks these variations belong to?*

Prompt 5: *Create a progression starting with "Come Together" by The Beatles, continuing with a segment found in a Rap song, and then continuing with another by Chuck Berry and Elvis Presley*

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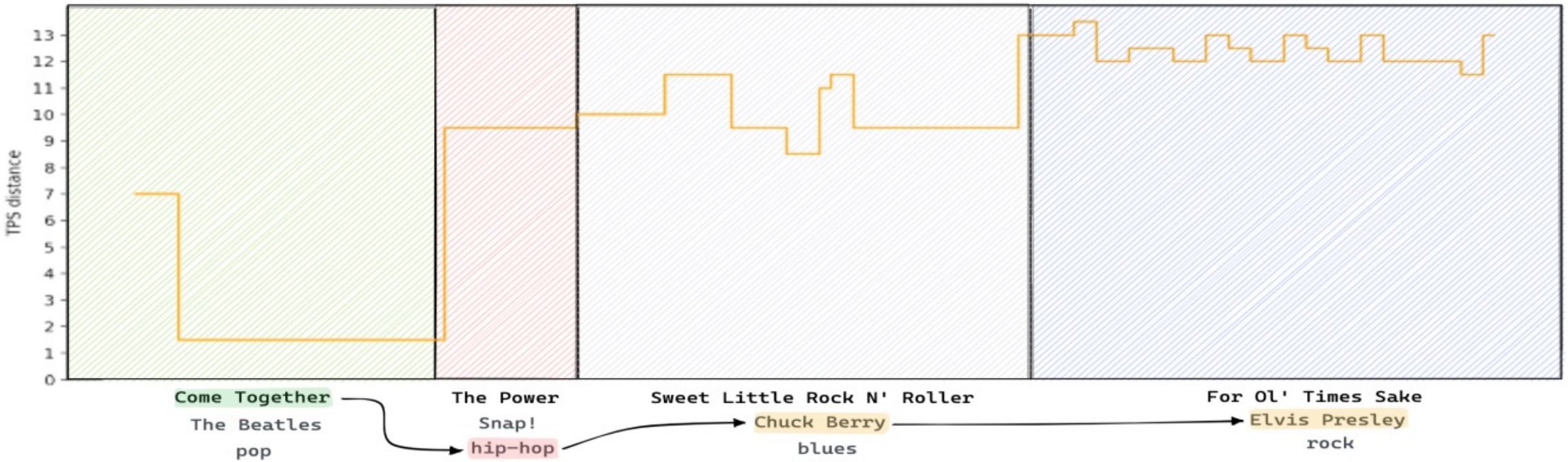
Avenues for Computational Creativity: 2 – Chord Generation



Avenues for Computational Creativity: 3 – Harmonic Similarity

From a musicological perspective, the KG can also be used to analyse similarity relations between tracks:

Prompt 6: *Given a track, which tracks contain patterns with a distance of less than 0.2?*

04

EXERCISE(s)

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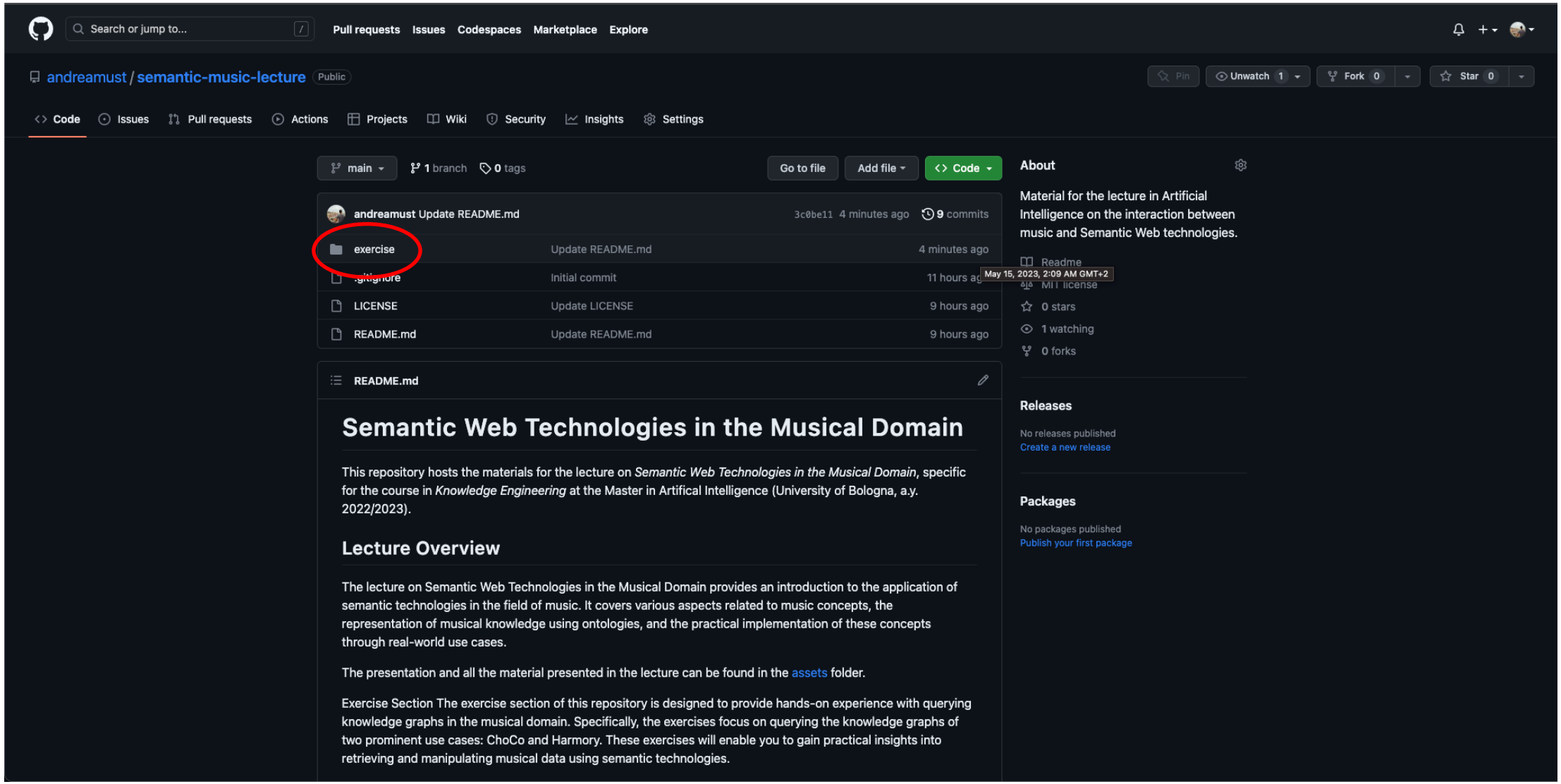
Task Description

- The exercise consists in **querying Knowledge Graphs you are not familiar with**
- The two knowledge graphs have been introduced during this lecture, namely:
  - *ChoCo*
  - *Harmory*
- You will be provided with a **sample query** and a few **competency questions**
- Working in pairs, you are asked to create SPARQL queries from:
  - One (or more) competency questions
  - New competency questions you will define (be creative!)

Exercise Link

https://github.com/andreamust/semantic-music-lecture

Exercise Link



Exercise Overview

1. Divide the class in **pairs**
2. **Pick one project** (*Harmory* or *ChoCo*)
3. **Fork** the repository
4. **Get familiar** with the Knowledge Graph and the Ontology
5. Write a SPARQL Query for one of the **predefined Competency Questions**
6. **Create you own** Competency Question
7. **Submit** you queries opening a **pull-request**

Querying ChoCo

```
SELECT DISTINCT ?observationValue ?startTime ?startTimeType ?duration ?durationType
WHERE {
  ?recording a mp:Recording ;
    mc:hasTitle "Michelle" ;
    jams:hasJAMSAnnotation ?annotation .
  ?annotation jams:includesObservation ?observation ;
    jams:hasAnnotationType "chord" .
  ?observation rdfs:label ?observationValue ;
    jams:hasMusicTimeInterval [jams:hasMusicTimeDuration [ jams:hasValue ?duration ; jams:hasValueType ?durationType ] ;
      jams:hasMusicTimeStartIndex [ jams:hasMusicTimeIndexComponent [ jams:hasValue ?startTime ; jams:hasValueType ?startTimeType  ]]] .
}
ORDER BY (?startTime)
LIMIT 10
```

Raw Response | Table | Pivot Table | Google Chart

Search: Show 50 entries

	observationValue	startTime	startTimeType	duration	durationType
1	N	"0.0"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.421247"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
2	F:min/5	"0.421247"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.994128"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
3	E:aug	"1.415375"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.959432"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
4	F:min7	"2.374807"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"1.010068"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
5	F:min6/5	"3.384875"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.986848"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
6	C#:maj7/3	"4.371723"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"1.085346"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
7	Bb:min/5	"5.457069"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.459543"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
8	C#/3	"5.916612"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"0.521956"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second
9	C	"6.438568"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second	"2.031476"^^xsd:float	http://w3id.org/polifonia/resource/ValueType/Second

Querying Harmory

```
4  PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
5
6  SELECT DISTINCT ?pattern ?title1 ?title2
7  WHERE {
8      ?pattern har:refersToSegment ?segment .
9      ?segment har:belongsToMusicalWork ?track1 .
10     ?track1 core:hasArtist ?artist1 ;
11             core:hasTitle ?title1 .
12     ?track2 core:hasArtist ?artist2 ;
13             core:hasTitle ?title2 .
14
15     FILTER (?title1 = "Michelle")
16     FILTER (?title2 = "Sunshine of Your Love")
17 }
18 LIMIT 10
```

Raw Response | Table | Pivot Table | Google Chart

Search: Show 50 entries

	pattern	title1	title2
1	http://w3id.org/polifonia/harmory/8.5_10.0_10.0_10.5_10.5_8.0_10.5_8.0_8.0_4.0_4.0_8.5_8.5_10.0_10.0_10.5_10.5_8.0_10.5_8.0	Michelle	Sunshine of Your Love
2	http://w3id.org/polifonia/harmory/4.0_4.0_8.5_8.5_8.5_10.0_10.0_10.5_10.5_8.0_10.5_8.0	Michelle	Sunshine of Your Love
3	http://w3id.org/polifonia/harmory/4.0_4.0_8.5_8.5_10.0_10.0_10.5_10.5_8.0_10.5_8.0	Michelle	Sunshine of Your Love
4	http://w3id.org/polifonia/harmory/8.0_0.0_0.0_0.0_0.0_8.0_8.0_7.0_7.0_5.5_5.5_0.0_0.0_0.0_7.5_0.5_1.0_6.5_6.5_5.5_5.5	Michelle	Sunshine of Your Love
5	http://w3id.org/polifonia/harmory/8.0_0.0_0.0_0.0_0.0_8.0_8.0_7.0_7.0_5.5_5.5_0.0_0.0_0.0_7.5_0.5_1.0_6.5_6.5_6.5_5.5_5.5	Michelle	Sunshine of Your Love
6	http://w3id.org/polifonia/harmory/8.0_0.0_7.5_0.5_0.5_1.0_6.5_6.5_5.5_5.5_4.0	Michelle	Sunshine of Your Love
7	http://w3id.org/polifonia/harmory/4.0_8.5_8.5_10.0_10.0_10.0_10.5_10.5_8.0_10.5_8.0_8.0_4.0_4.0_8.5_8.5_10.0_10.0_10.0	Michelle	Sunshine of Your Love
8	http://w3id.org/polifonia/harmory/7.5_0.5_1.0_6.5_6.5_7.0_5.5_5.5_4.0_4.0_8.5	Michelle	Sunshine of Your Love

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