Universitat Pompeu Fabra Barcelona

Automatic Harmonic Analysis of Classical String Quartets From Symbolic Score

Néstor Nápoles López

Supervisors:
Xavier Serra / Rafael Caro

Music Technology Group

compmusic

Summary

Reproducing state of the art harmonic analysis

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Reproducing state of the art harmonic analysis

Creating dataset of manual harmonic analysis annotations of string quartets

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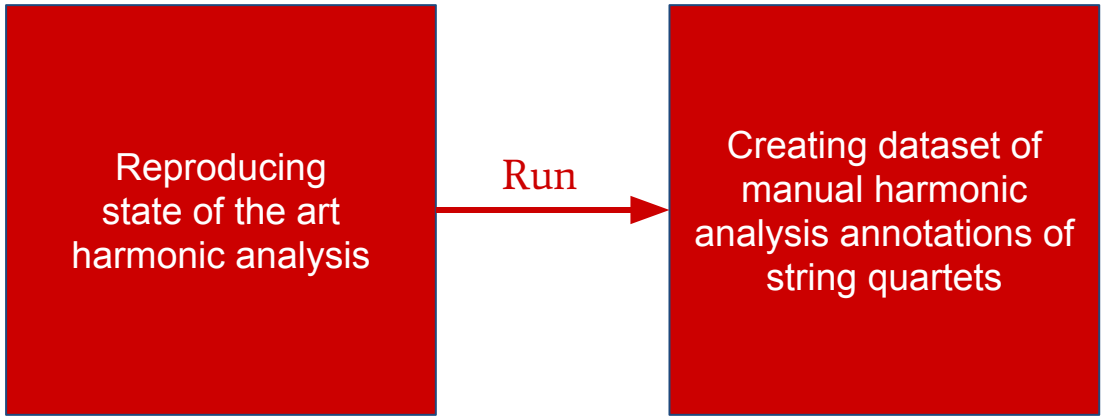
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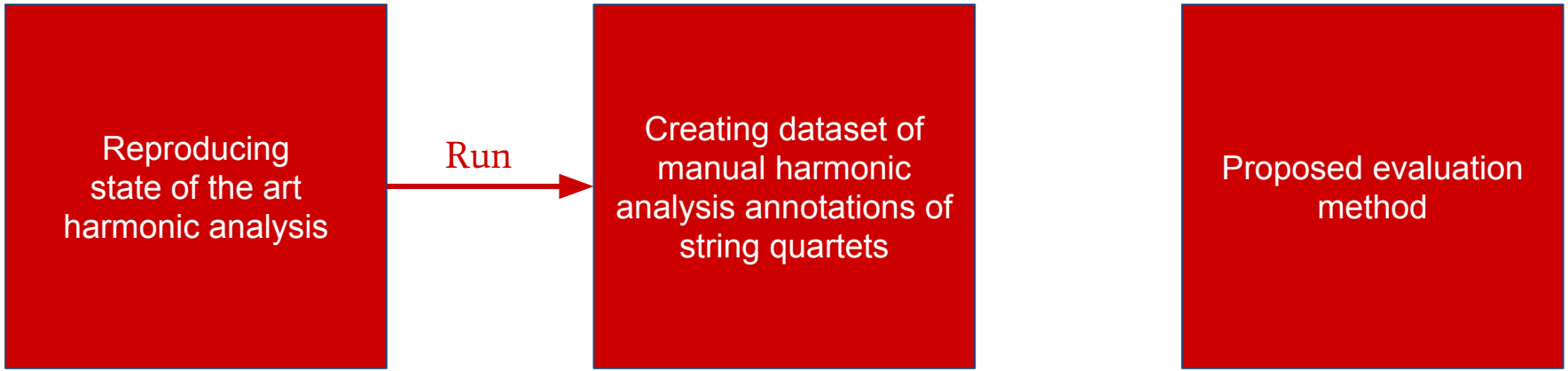
Reproducing state of the art harmonic analysis
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Creating dataset of manual harmonic analysis annotations of string quartets
Proposed evaluation method

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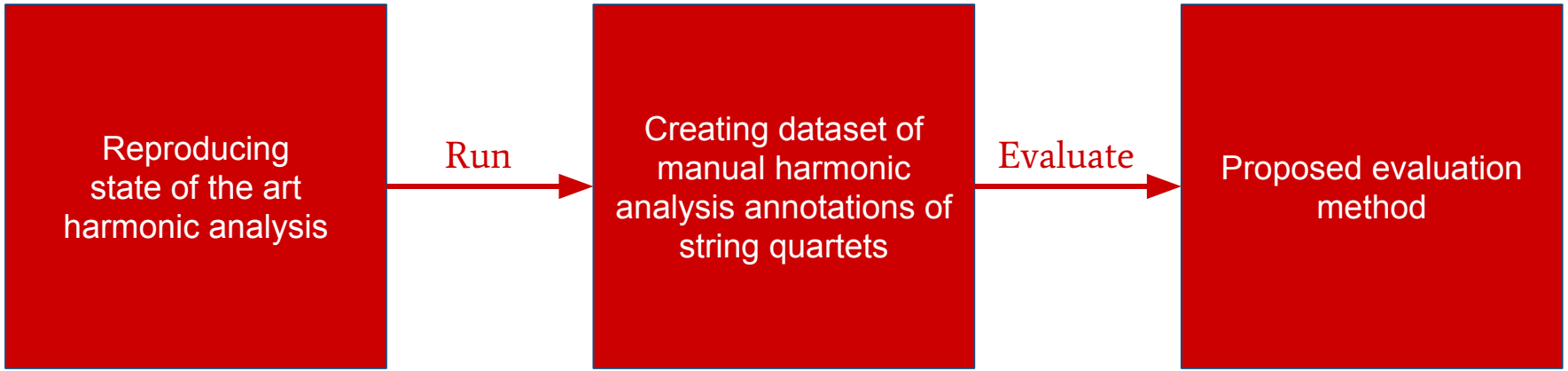
Reproducing state of the art harmonic analysis
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Creating dataset of manual harmonic analysis annotations of string quartets
Evaluate
Proposed evaluation method

Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

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Automatic Harmonic Analysis

Analysis

Interpreting the structures in music,

resolving into relatively simpler elements,

investigating the relevant functions of those elements.

Ian D. Bent and Anthony Pople. "Analysis." Grove Music Online. Oxford Music Online. Oxford University Press. Web. 28 Jun. 2017. <http://www.oxfordmusiconline.com/subscriber/article/grove/music/41862>

Automatic Harmonic Analysis

Harmony

The simultaneous sounding of notes.

"Harmony." The Oxford Dictionary of Music, 2nd ed. rev. Ed. Michael Kennedy. Oxford Music Online. Oxford University Press. Web. 28 Jun. 2017. <http://www.oxfordmusiconline.com/subscriber/article/opr/t237/e4724>.

Automatic Harmonic Analysis

Harmonic analysis

Interpreting the **harmonic** structures in music,

resolving into relatively simpler elements**, i.e., labels,**

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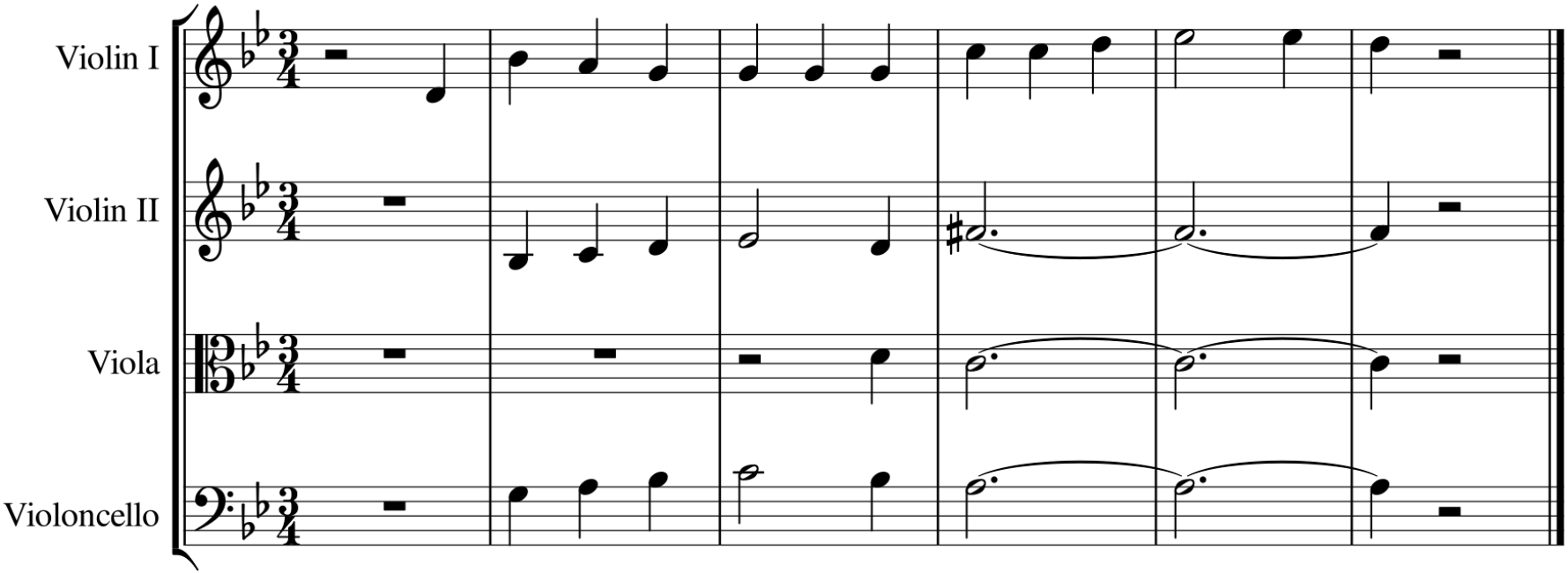

Excerpt from Joseph Haydn's Op.20 No.3 - II. Menuetto: Allegretto, mm. 1-6

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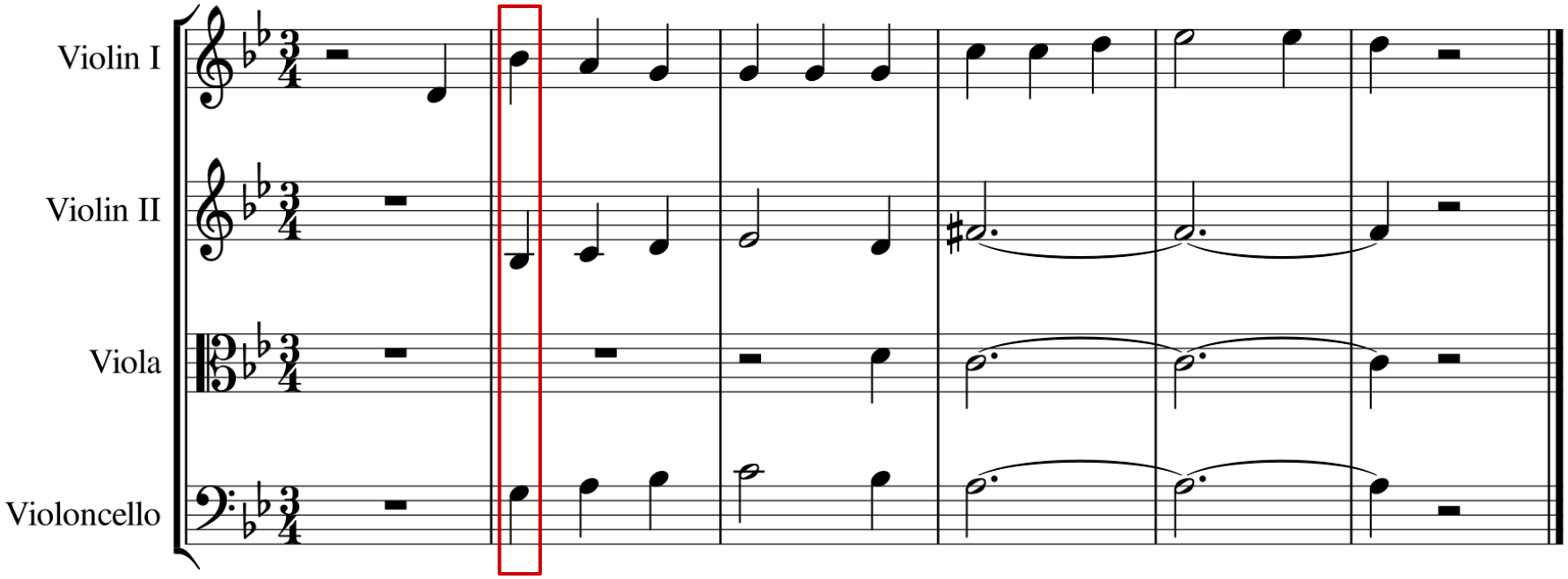
Automatic Harmonic Analysis



Harmony

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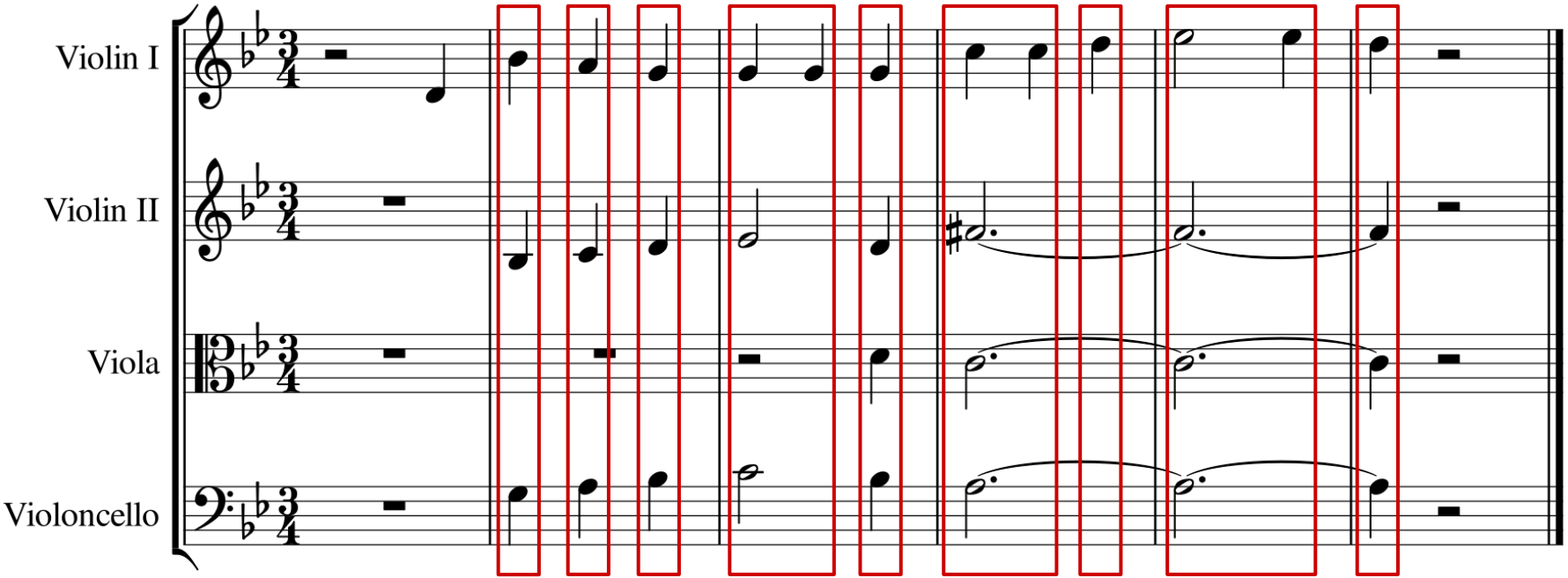
Automatic Harmonic Analysis



Harmonic structures

Automatic Harmonic Analysis

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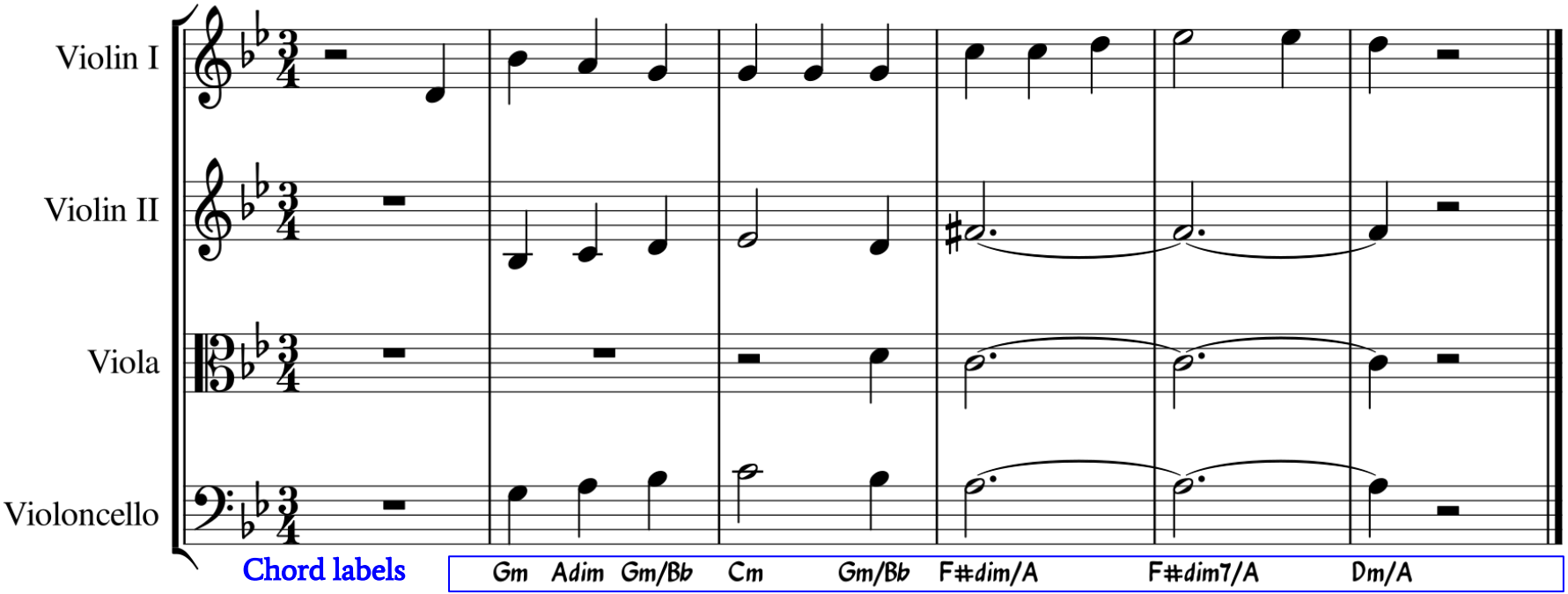

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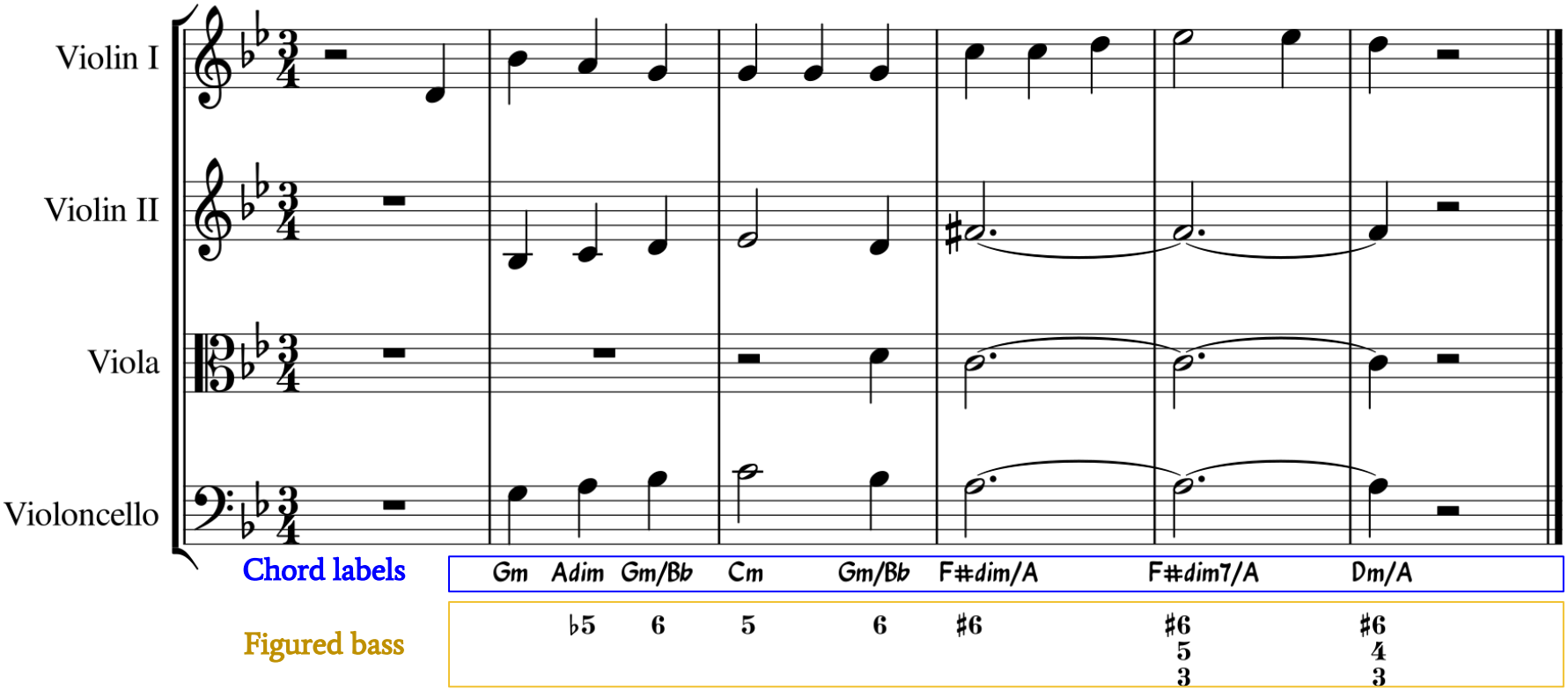

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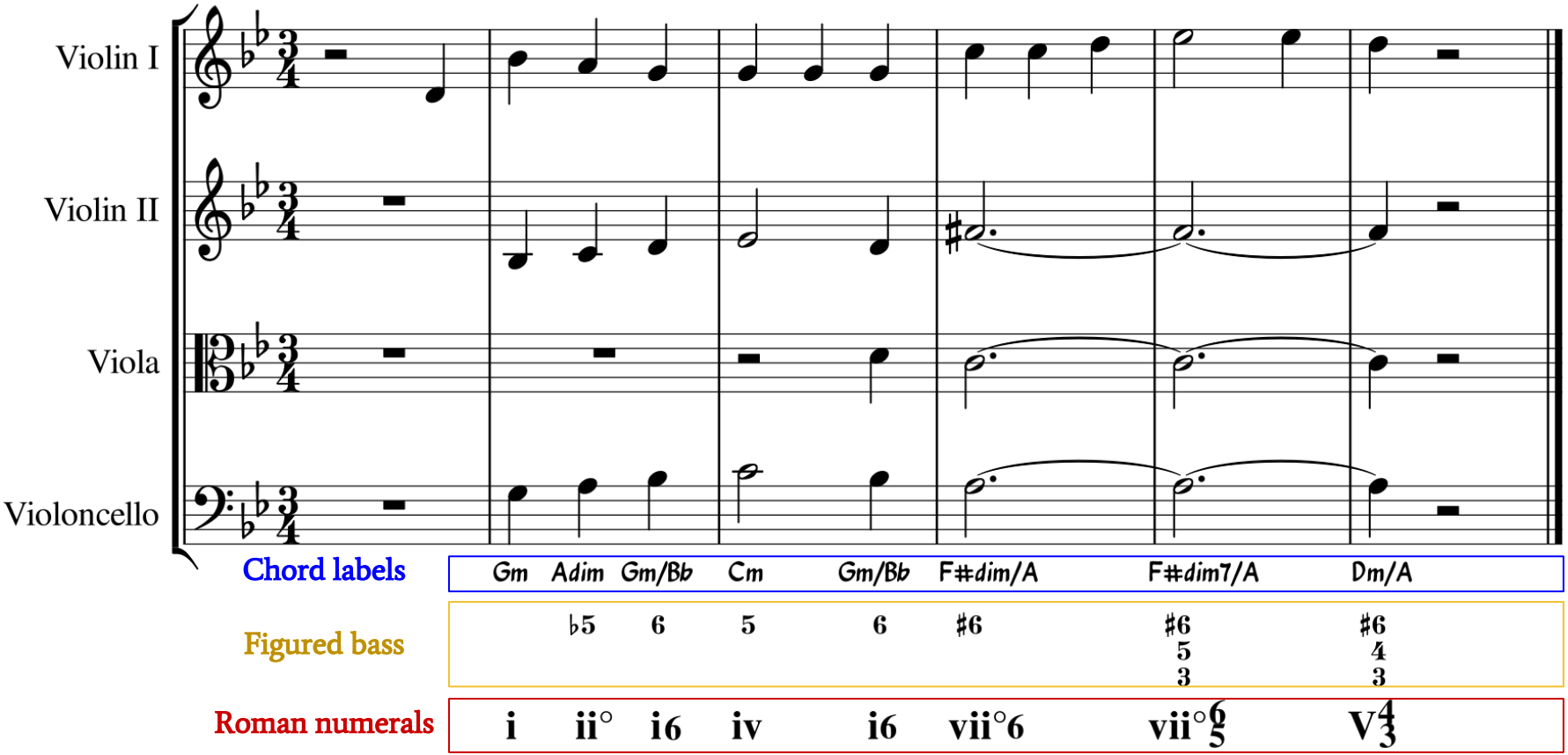

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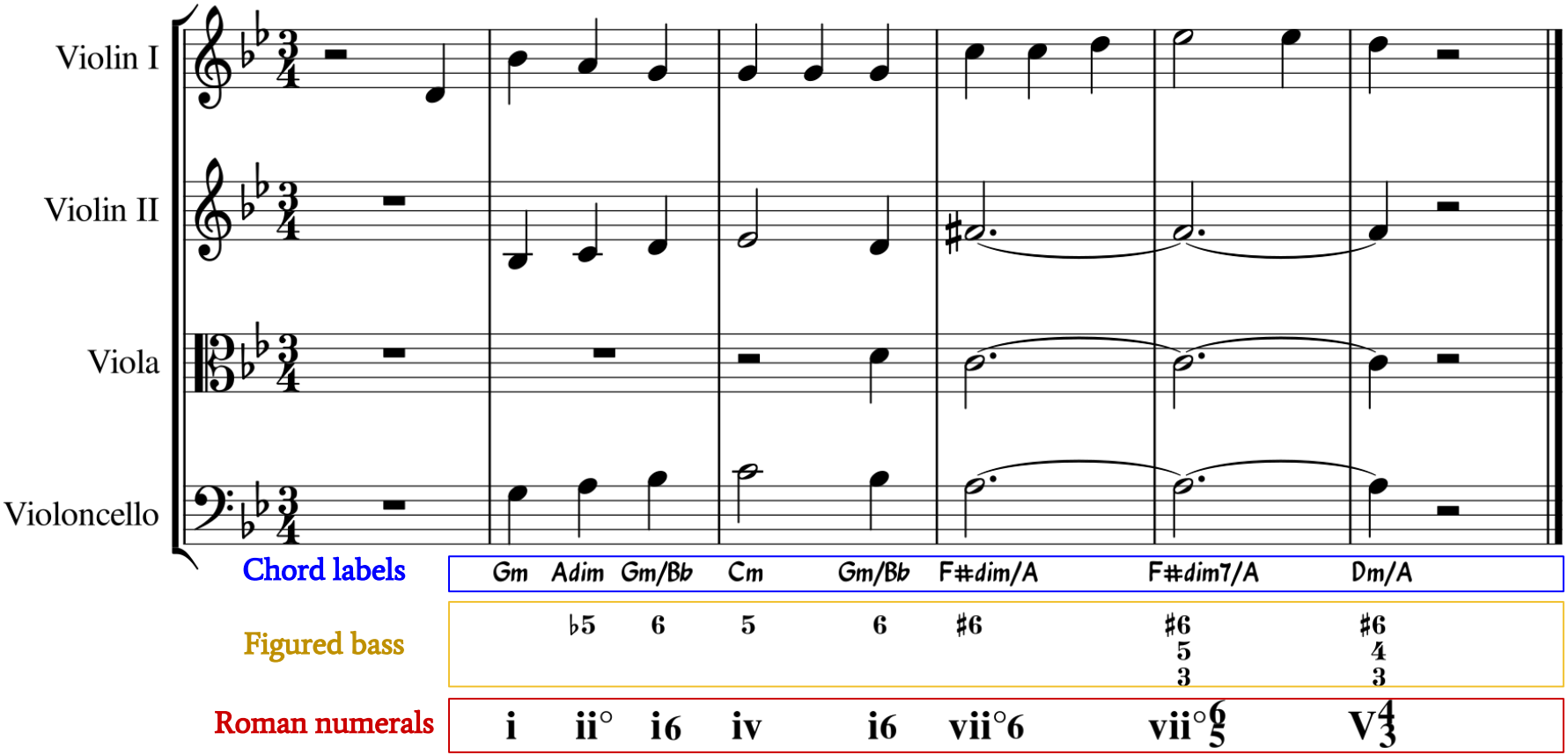

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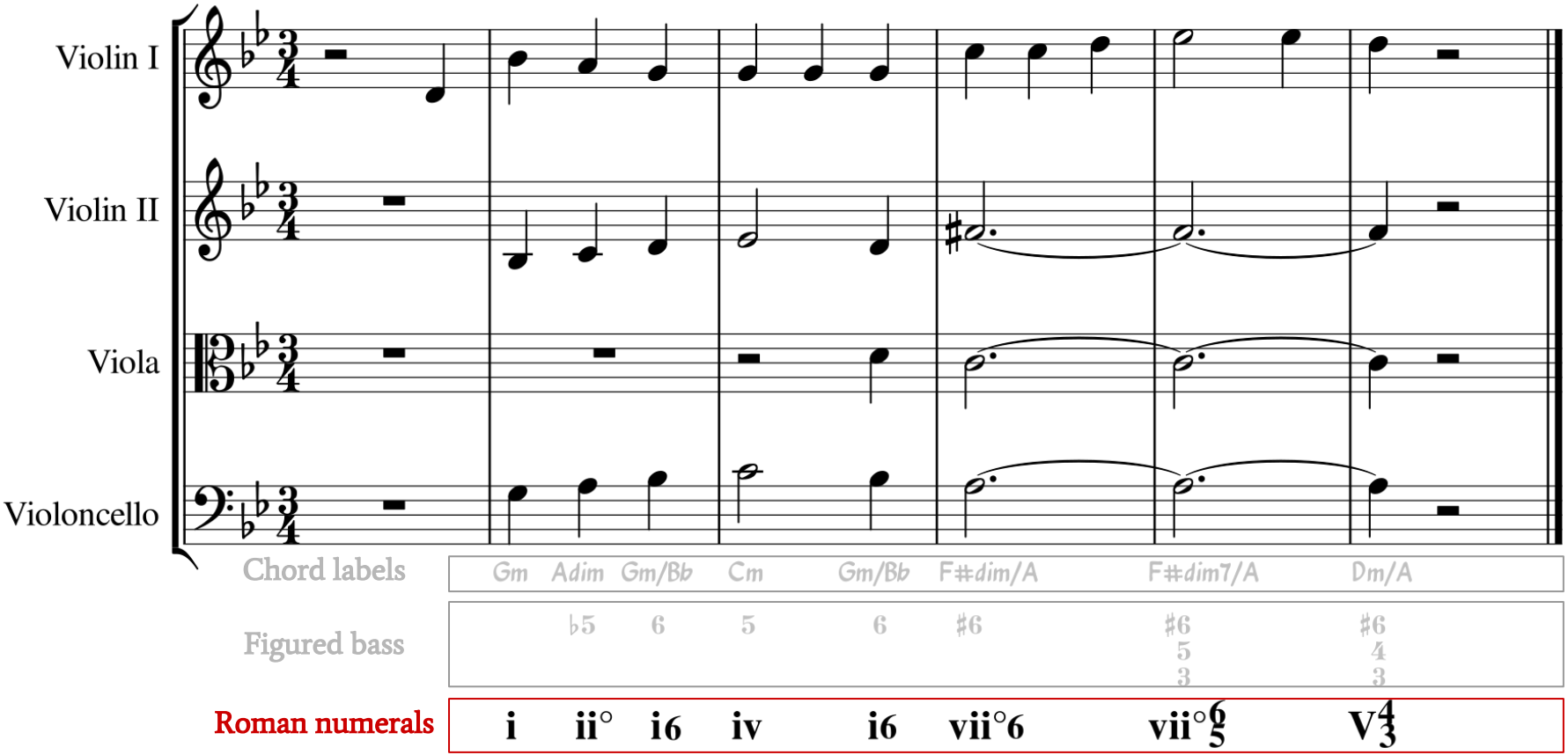

Automatic Harmonic Analysis

Harmonic analysis

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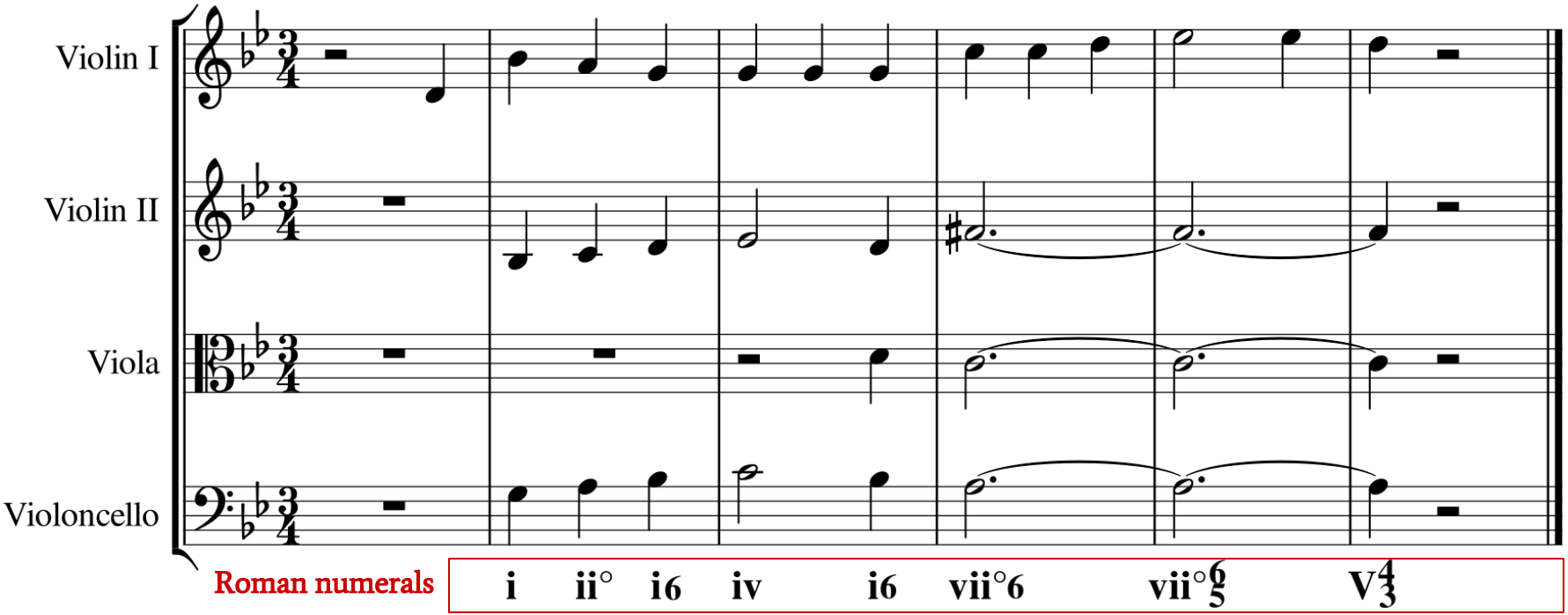

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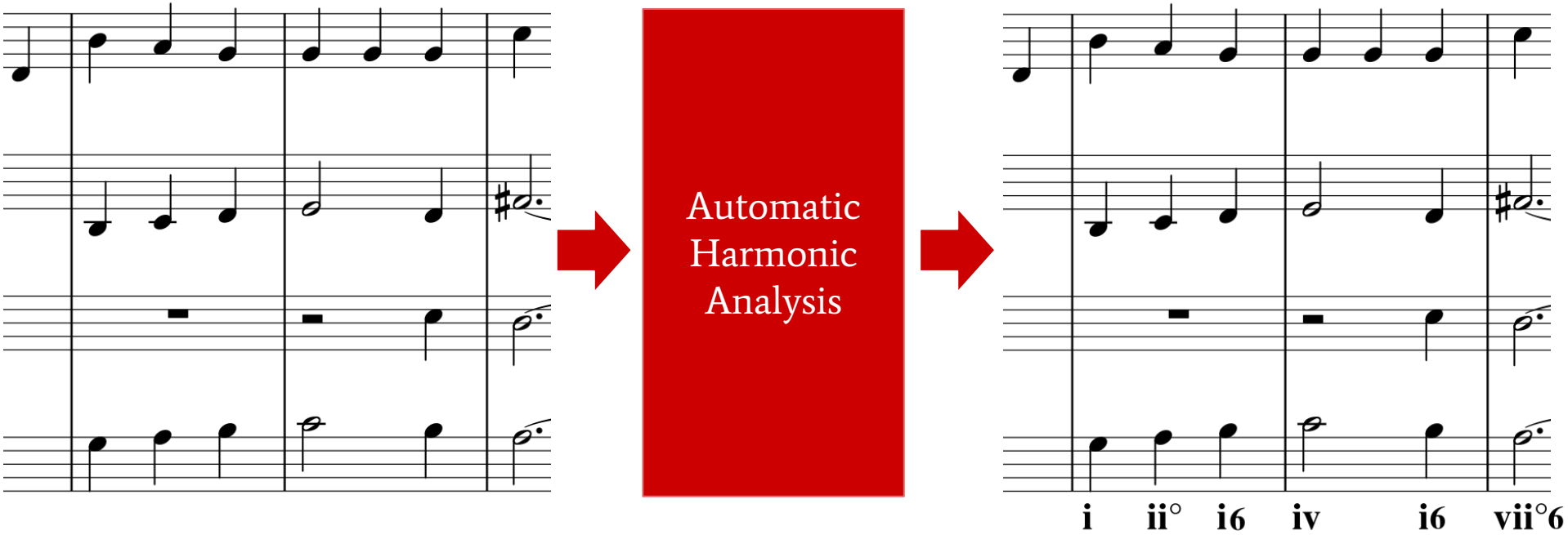

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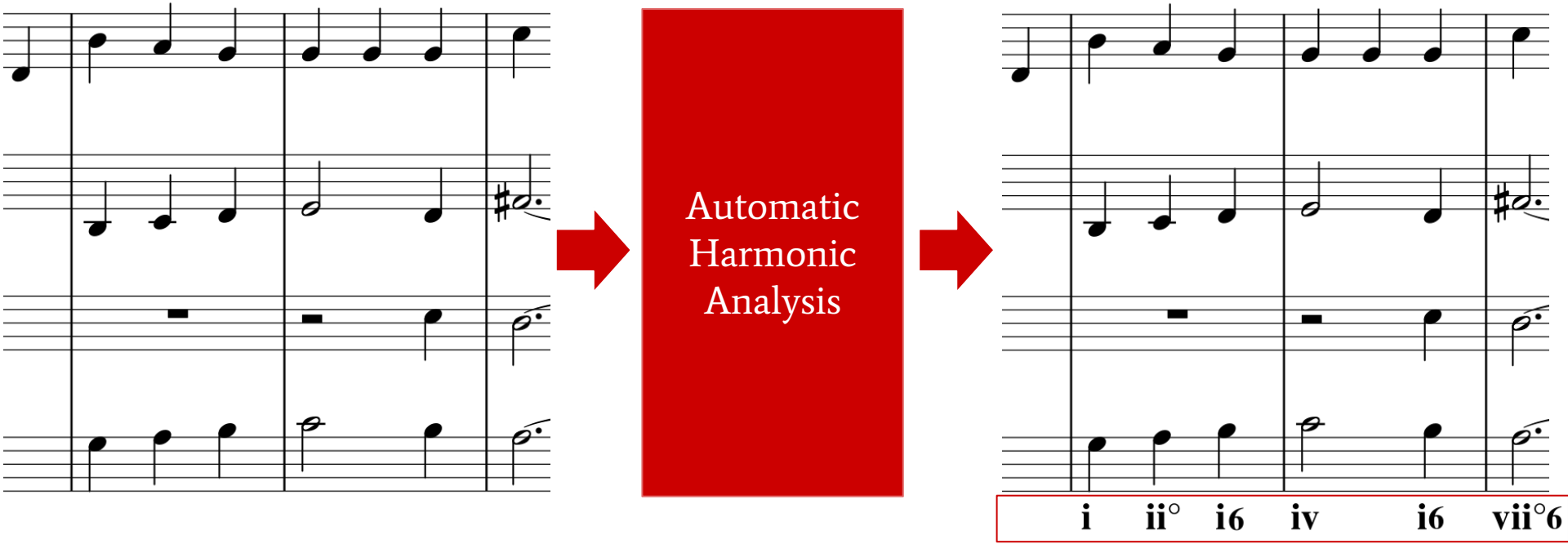

Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

Dataset

Six string quartets
from Joseph Haydn

Op.20 No.1
Op.20 No.2
Op.20 No.3
Op.20 No.4
Op.20 No.5
Op.20 No.6

Dataset

Six string quartets
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Six string quartets
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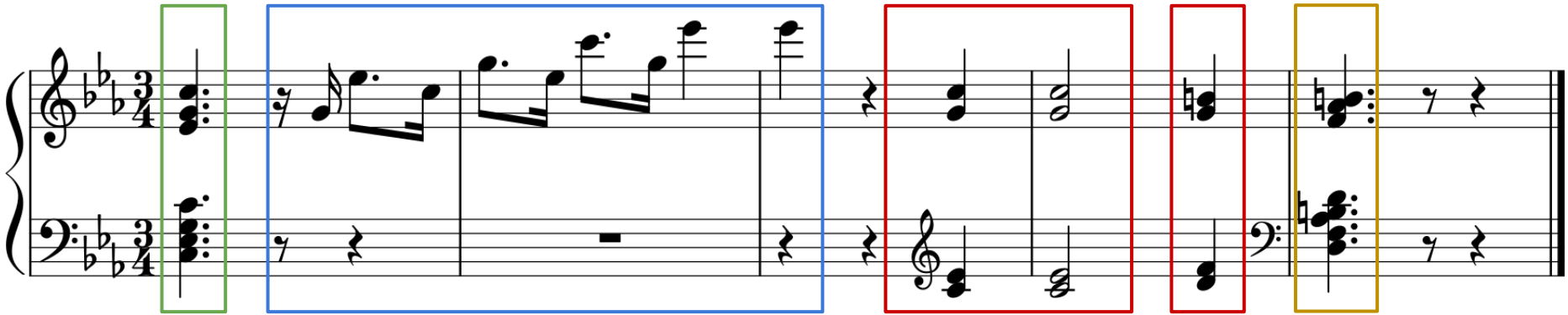
Op.20 No.1
Op.20 No.2
Op.20 No.3
Op.20 No.4
Op.20 No.5
Op.20 No.6

Dataset

The String Quartet

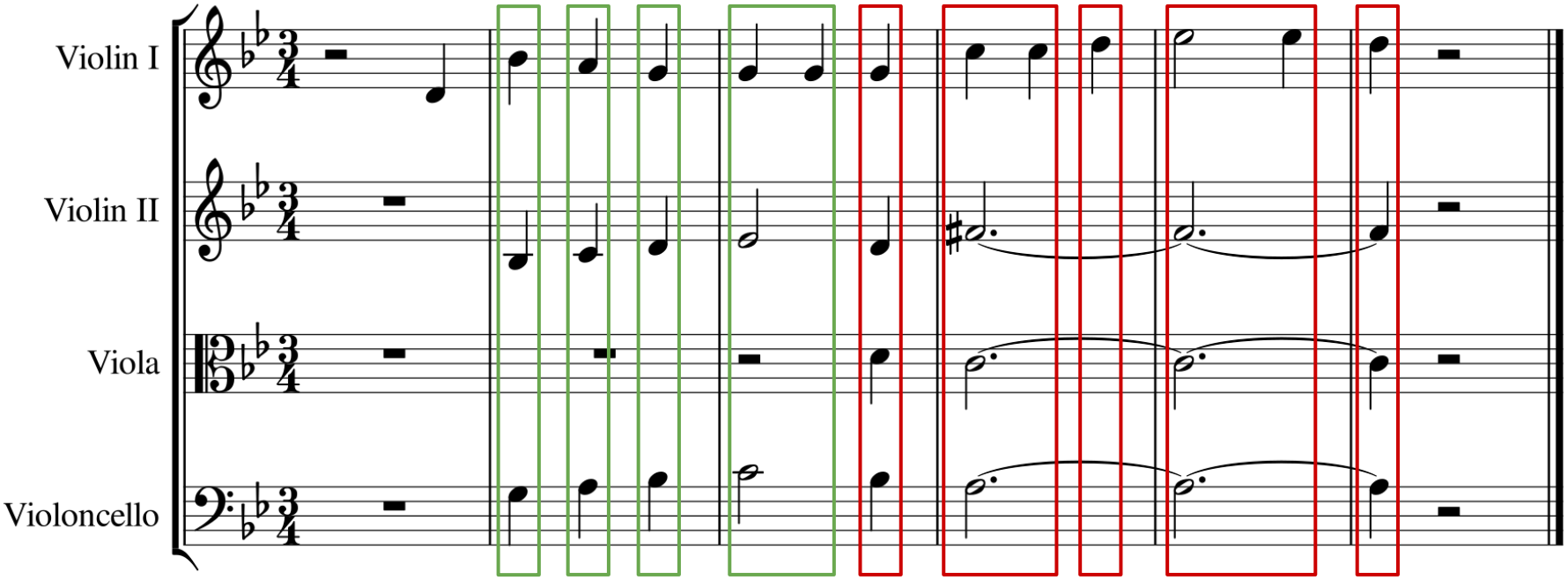
- Require a broad knowledge of harmony
- One of the most prominent genres developed during the Classical period
- Four voices (almost) all the time
- Explicit stream segregation
  - Each voice is separated explicitly in the symbolic score
  - Its own midi channel, spine, node, etc.

Dataset



Excerpt from Ludwig van Beethoven's Sonata Op.10 No.1 - I. Molto Allegro e con brio, mm. 1-5

Dataset



Dataset

Joseph Haydn

- Colloquially named *“The father of the string quartet”*
- Major figure of the classical period of western art music
  - Exemplifies many of the characteristic features of the style
- Mentor of Wolfgang Amadeus Mozart and Ludwig van Beethoven
  - The two other major figures of the classical period

Dataset

Six string quartets Op.20

- They provided innovations to the compositional technique of string quartets
- Good distribution of musical forms and structure
  - Sonata movements, fugues, theme and variations, minuets, etc.
- Mastery in the use of musical elements
  - Syncopation, imitation, counterpoint
- Representative style, less experimental than later works, e.g., Op.33

Dataset

KernScores
http://kern.ccarh.org/

Virtual library of musical scores in Humdrum **kern syntax

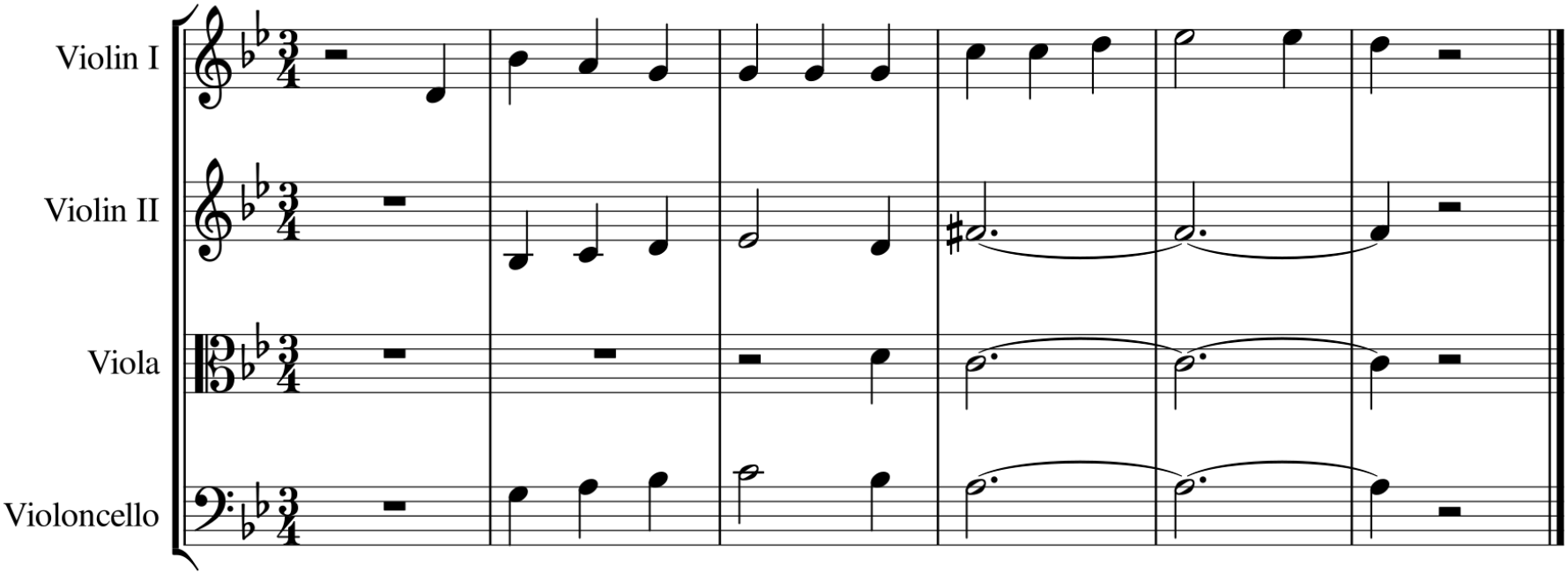
Allocates musical scores for 19 out of 24 pieces of the String quartets Op.20

Dataset

Humdrum **kern syntax

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

Automatic Harmonic Analysis



Excerpt from Joseph Haydn's Op.20 No.3 - II. Menuetto: Allegretto, mm. 1-6

Dataset

Each column represents a voice

Humdrum **kern syntax

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

Dataset

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Allocates musical scores for **19 out of 24 pieces** of the String quartets Op.20

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Transcribing 5 remaining scores

Dataset

The Humdrum **harm syntax
http://www.music-cog.ohio-state.edu/Humdrum/representations/harm.rep.html

Very detailed syntax for roman numerals

Allows to annotate roman numerals in a machine-friendly

and (sort of) human-friendly format

upf. Music Technology Group

Dataset

Humdrum **kern, **harm syntax

**harm	**commentary	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:	*g:
*	*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	.	2r	2r	2r	2r
.	.	4r	4r	4r	4d
=1	=1	=1	=1	=1	=1
i	.	4G	2.r	4B-	4b-
iio	Not really diminished, missing the fifth	4A	.	4c	4a
ib	.	4B-	.	4d	4g
=2	=2	=2	=2	=2	=2
iv	.	2c	2r	2e-	4g
.	.	.	.	.	4g
ib	.	4B-	4d	4d	4g
=3	=3	=3	=3	=3	=3
viiob	.	[2.A	[2.c	[2.f#	4cc
.	.	.	.	.	4cc
V7c	.	.	.	.	4dd
=4	=4	=4	=4	=4	=4
viioD7b	.	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	.	4ee-
=5	=5	=5	=5	=5	=5
V7c	.	4A]	4c]	4f#]	4dd
.	.	2r	2r	2r	4r
.	.	.	.	.	4d

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Dataset

Humdrum **kern, **harm syntax

Manual annotation of harmony

**harm	**commentary	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:	*g:
*	*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	.	2r	2r	2r	2r
.	.	4r	4r	4r	4d
=1	=1	=1	=1	=1	=1
i	.	4G	2.r	4B-	4b-
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=2	=2	=2	=2	=2	=2
iv	.	2c	2r	2e-	4g
.	.	.	.	.	4g
ib	.	4B-	4d	4d	4g
=3	=3	=3	=3	=3	=3
viiob	.	[2.A	[2.c	[2.f#	4cc
.	.	.	.	.	4cc
V7c	.	.	.	.	4dd
=4	=4	=4	=4	=4	=4
viioD7b	.	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	.	4ee-
=5	=5	=5	=5	=5	=5
V7c	.	4A]	4c]	4f#]	4dd
.	.	2r	2r	2r	4r
.	.	.	.	.	4d

Dataset

Summary of the dataset

Six string quartets

24 pieces of music

146 pages of music notation (Altmann Edition)

4961 roman numerals annotations

Commentaries (ambiguous sections, structural analysis, etc.)

https://github.com/napulen/haydn_op20_harm

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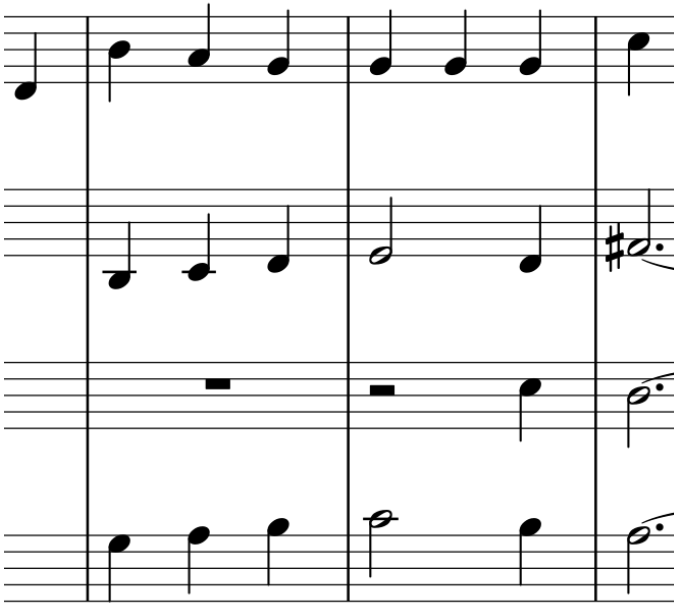
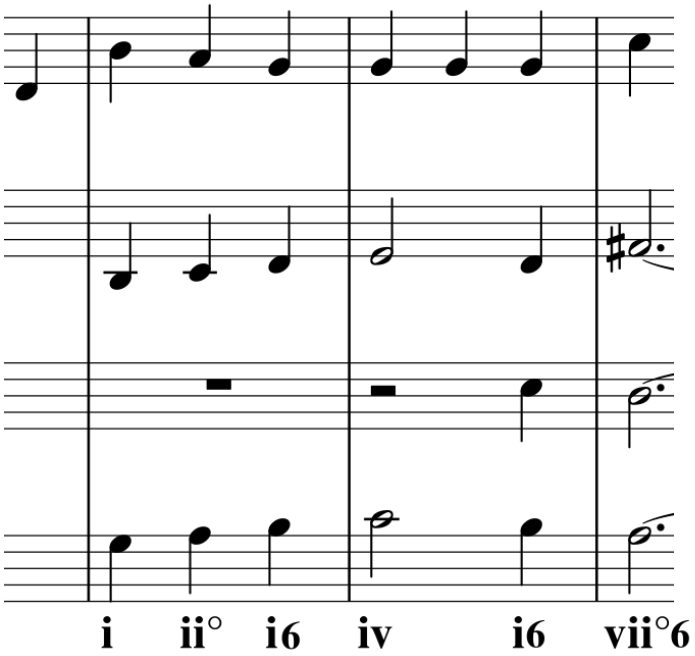
Running the analysis



Automatic Harmonic Analysis



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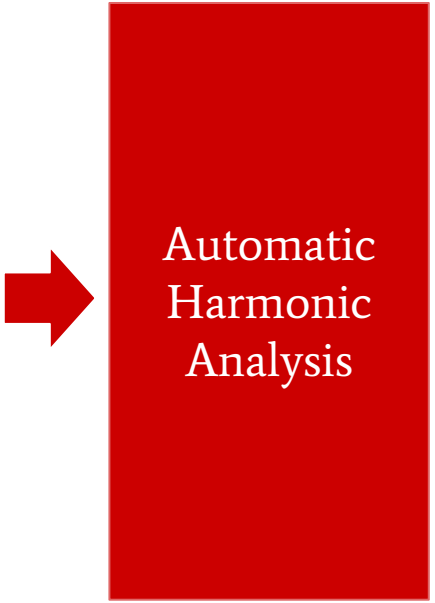
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d



**harm	**kern	**kern	**kern	**kern
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*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viioD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

Running the analysis

Approach	Type of Model	Year	Implementation	Available
Terry Winograd	Grammar-based	1968	LISP	No
John Maxwell	Rule-based	1992*	LISP	No
David Temperley	Rule-based	1997**	C	Yes
Christopher Raphael	Probabilistic	2003	C	Partially
Plácido Illescas	Rule-based	2008	Java	Partially

** Maxwell presented this work at his PhD dissertation in 1984. However, most researchers cite the publication from 1992 in the book "Understanding music with AI".*

***A lot of work has been done after Temperley in 1997, traceable to as recent as 2017. This reference is just the starting point for this approach.*

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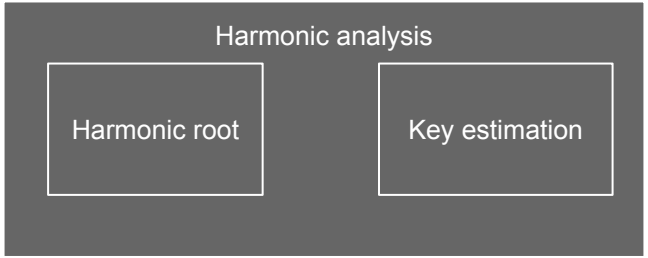
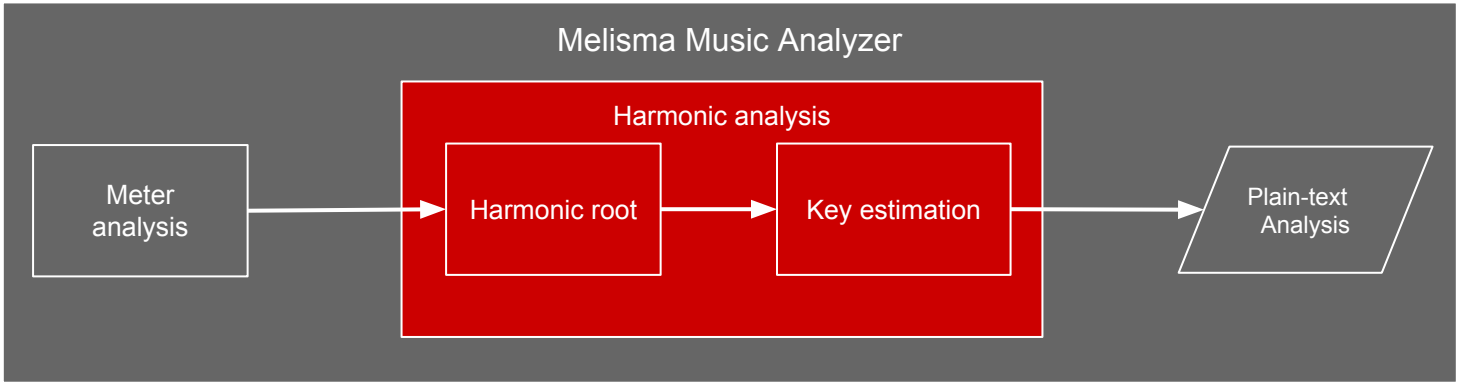


Running the analysis



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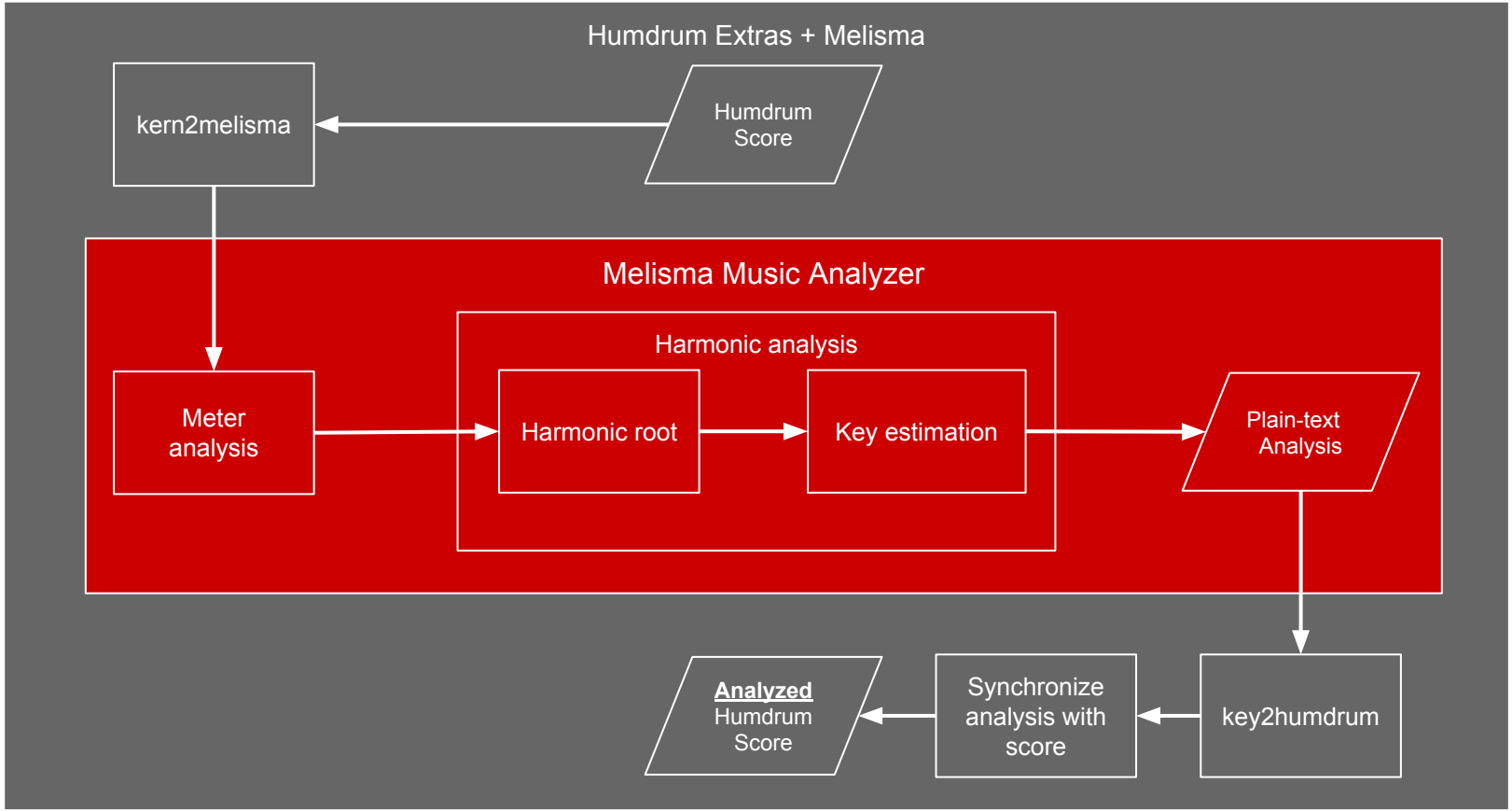
Running the analysis



David Temperley + Daniel Sleator + Craig Sapp

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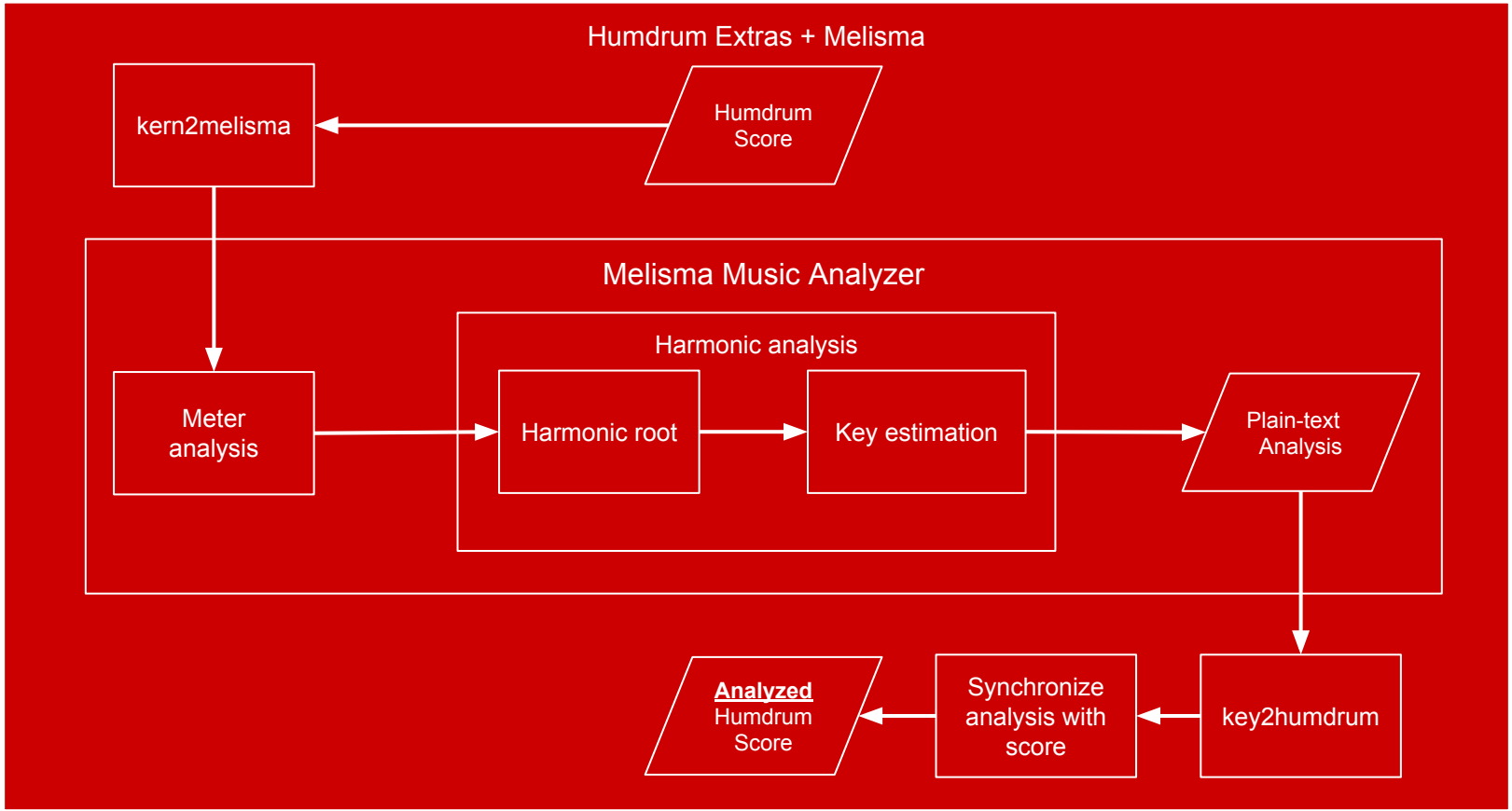
Running the analysis



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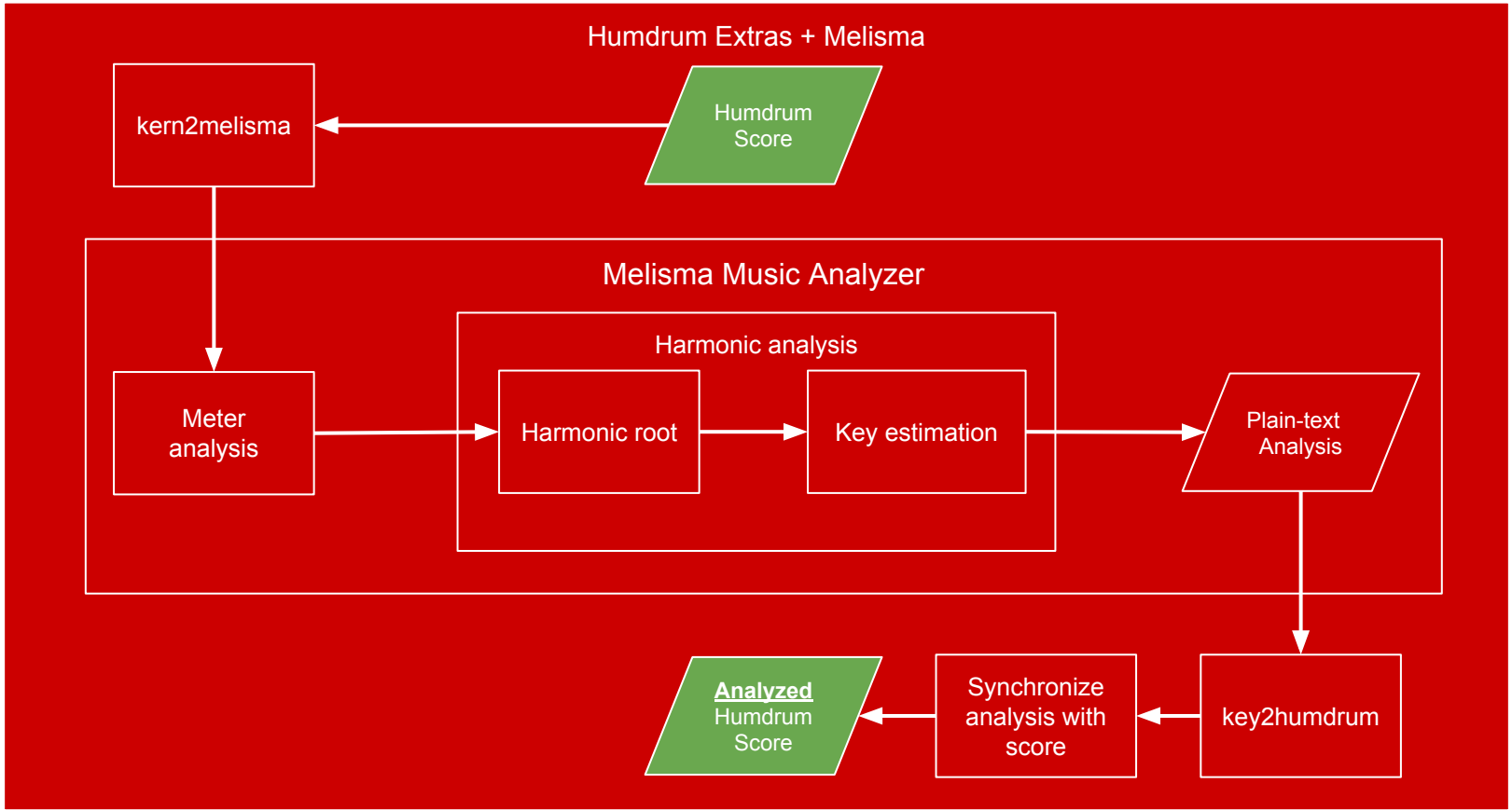
Running the analysis



David Temperley + Daniel Sleator + Craig Sapp

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Running the analysis

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

Automatic Harmonic Analysis

**harm	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:
*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viioD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

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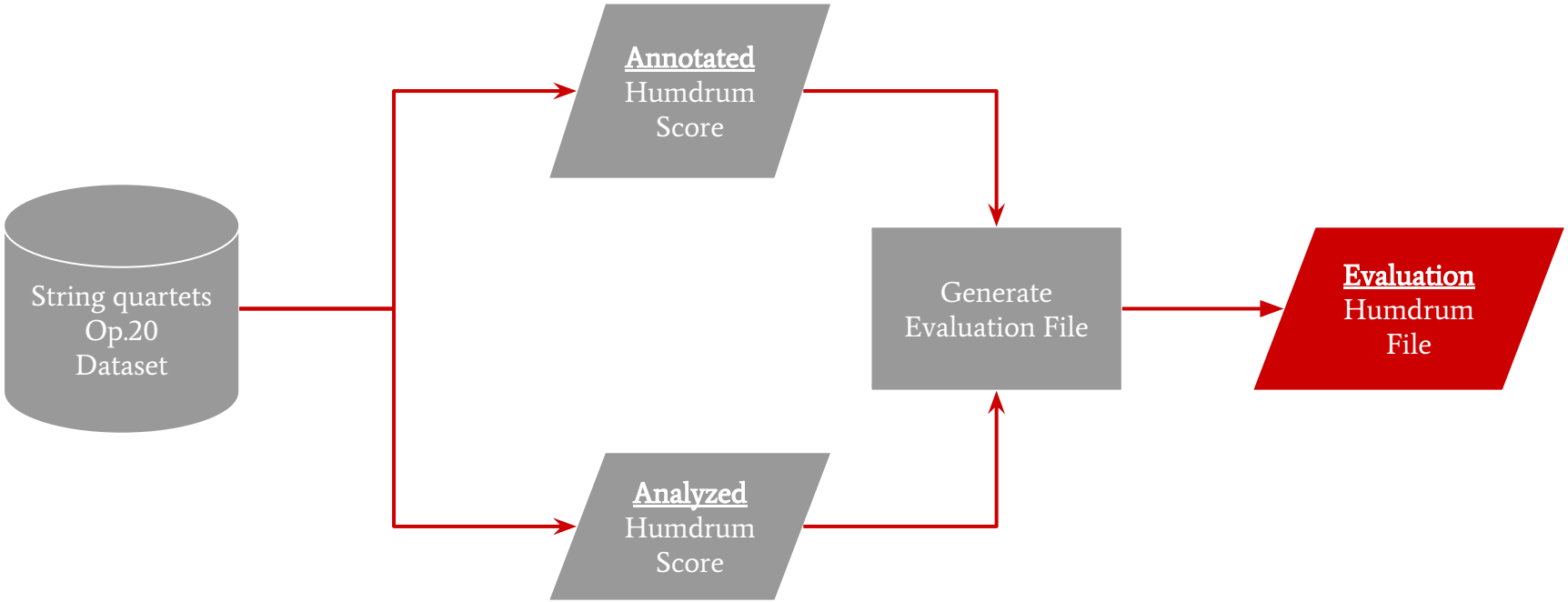
Running the analysis

**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:
*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4
2r	2r	2r	2r
4r	4r	4r	4d
=1	=1	=1	=1
4G	2.r	4B-	4b-
4A	.	4c	4a
4B-	.	4d	4g
=2	=2	=2	=2
2c	2r	2e-	4g
.	.	.	4g
4B-	4d	4d	4g
=3	=3	=3	=3
[2.A	[2.c	[2.f#	4cc
.	.	.	4cc
.	.	.	4dd
=4	=4	=4	=4
2.A_	2.c_	2.f#_	2ee-
.	.	.	4ee-
=5	=5	=5	=5
4A]	4c]	4f#]	4dd
2r	2r	2r	4r
.	.	.	4d

Humdrum Extras + Melisma Music Analyzer

**harm	**kern	**kern	**kern	**kern
*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]	*k[b-e-]
*g:	*g:	*g:	*g:	*g:
*	*clefF4	*clefC3	*clefG2	*clefG2
*M3/4	*M3/4	*M3/4	*M3/4	*M3/4
.	2r	2r	2r	2r
.	4r	4r	4r	4d
=1	=1	=1	=1	=1
i	4G	2.r	4B-	4b-
iio	4A	.	4c	4a
ib	4B-	.	4d	4g
=2	=2	=2	=2	=2
iv	2c	2r	2e-	4g
.	.	.	.	4g
ib	4B-	4d	4d	4g
=3	=3	=3	=3	=3
viiob	[2.A	[2.c	[2.f#	4cc
.	.	.	.	4cc
V7c	.	.	.	4dd
=4	=4	=4	=4	=4
viioD7b	2.A_	2.c_	2.f#_	2ee-
.	.	.	.	4ee-
=5	=5	=5	=5	=5
V7c	4A]	4c]	4f#]	4dd
.	2r	2r	2r	4r
.	.	.	.	4d

Running the analysis



Structure of the presentation

1. Automatic Harmonic Analysis
2. The dataset: Six string quartets Op.20, Joseph Haydn
3. Running the analysis
4. Evaluation
5. Results
6. Contributions

Evaluation

Evaluation file

It is a valid Humdrum file. However, it is no longer a musical score

Contains two pairs of **harm **root spines

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Evaluation

**harm	**root	**harm	**root
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
=1	=1	=1	=1
i	g	.	.
.	.	.	.
iio	a	iv	f
.	.	.	.
ib	g	.	.
.	.	.	.
=2	=2	=2	=2
iv	c	ib	c
.	.	.	.
.	.	V7c	g
.	.	.	.
ib	g	.	.
.	.	.	.

Evaluation

Manual annotations

**harm	**root
.	.
.	.
.	.
.	.
.	.
.	.
=1	=1
i	g
.	.
iio	a
.	.
ib	g
.	.
=2	=2
iv	c
.	.
.	.
.	.
ib	g
.	.

**harm	**root
.	.
.	.
.	.
.	.
.	.
.	.
=1	=1
.	.
.	.
iv	f
.	.
.	.
.	.
=2	=2
ib	c
.	.
V7c	g
.	.
.	.
.	.

Automatic analysis

Evaluation

Summary of evaluation

Normalization of time units,

resolution of harmonic roots,

string comparison of harmonic roots per time unit

output the percentage of matches over the time units

Evaluation

Normalization of time units

Shortest note of the musical score

Evaluation

Resolution of harmonic roots

```
Cmajor: I      ==     Gmajor: IV

Cmajor: V/V    ==     Gmajor: V

Cmajor: V7/vi  ==     Dminor: V7/V
```

Evaluation

Resolution of harmonic roots

Developed a parser for the **harm syntax
https://github.com/napulen/harmparser

Input a **harm expression and output its characteristics

Using this to resolve the harmonic roots of different labels,
even if they are relative to different keys

Structure of the presentation

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Results

	Matching time units	Total time units	Score
Op.20 No.1			
I	2261	3489	64.80%
II	221	805	27.45%
III	1319	1730	76.24%
IV	332	1289	25.76%
Op.20 No.2			
I	1254	5137	24.41%
II	1119	2017	55.48%
III	713	1033	69.02%
IV	309	1945	15.89%
Op.20 No.3			
I	2426	4322	56.13%
II	121	535	22.62%
III	3386	4069	83.21%
IV	535	1681	31.83%
Op.20 No.4			
I	2464	3663	67.27%
II	1992	3922	50.79%
III	65	223	29.15%
IV	1651	6289	26.25%
Op.20 No.5			
I	4950	7729	64.04%
II	793	1201	66.03%
III	2617	3061	85.49%
IV	798	1473	54.18%
Op.20 No.6			
I	1808	3985	45.37%
II	6217	7585	81.96%
III	405	505	80.20%
IV	1361	3041	44.76%

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2. Finding, and in some cases, fixing issues
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    a. With help of Rafael Caro for the first movement of each quartet
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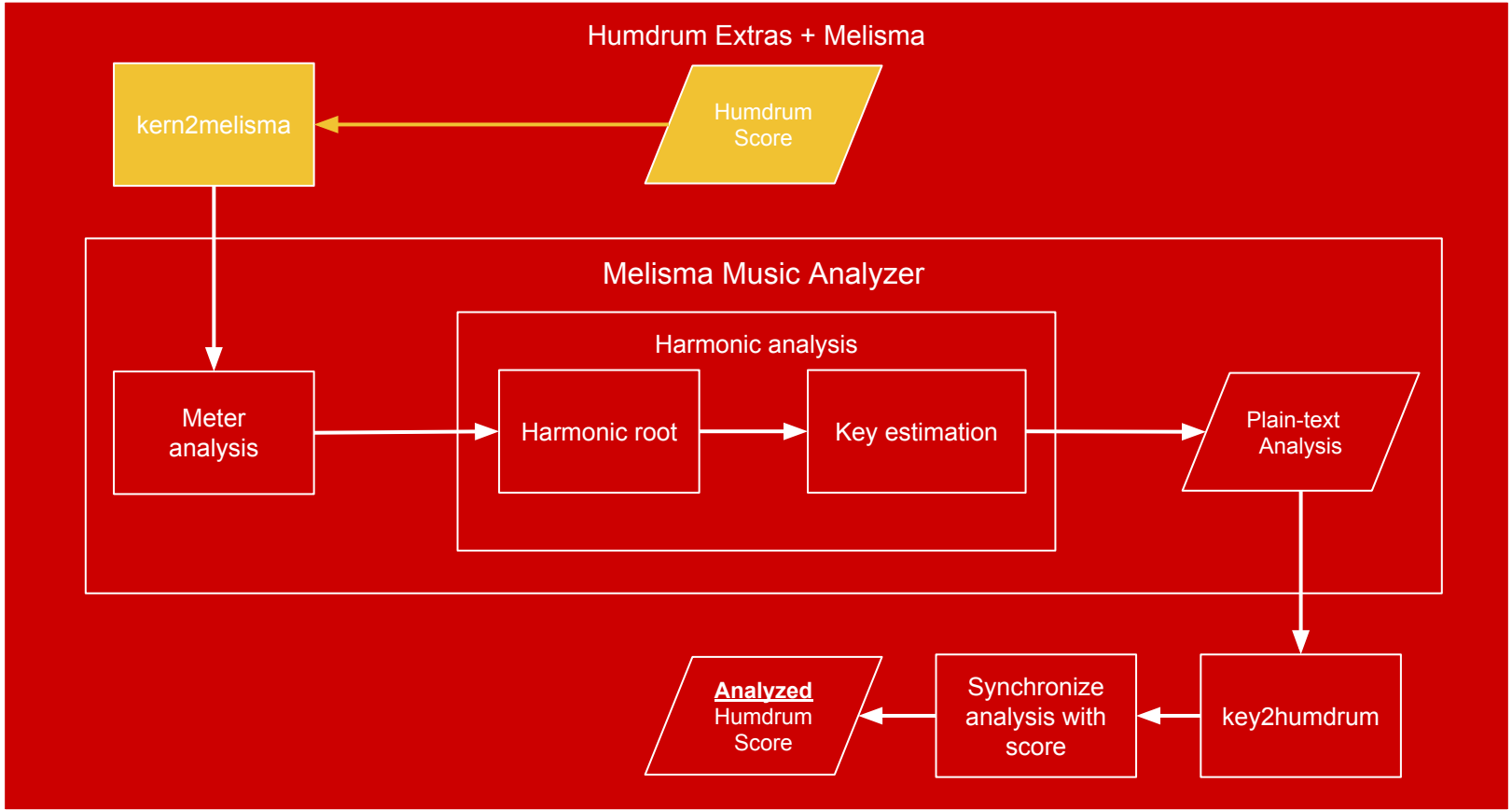

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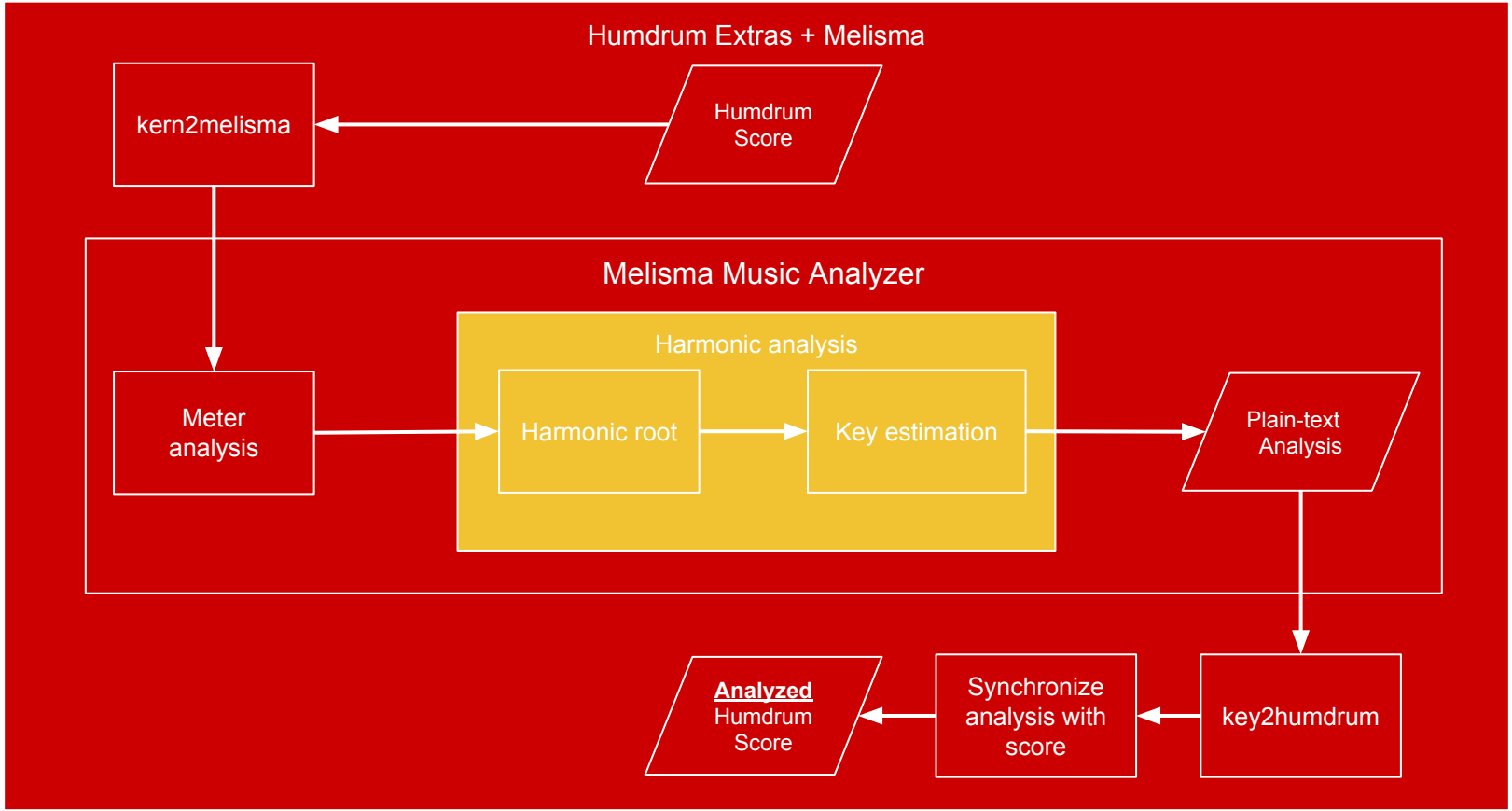

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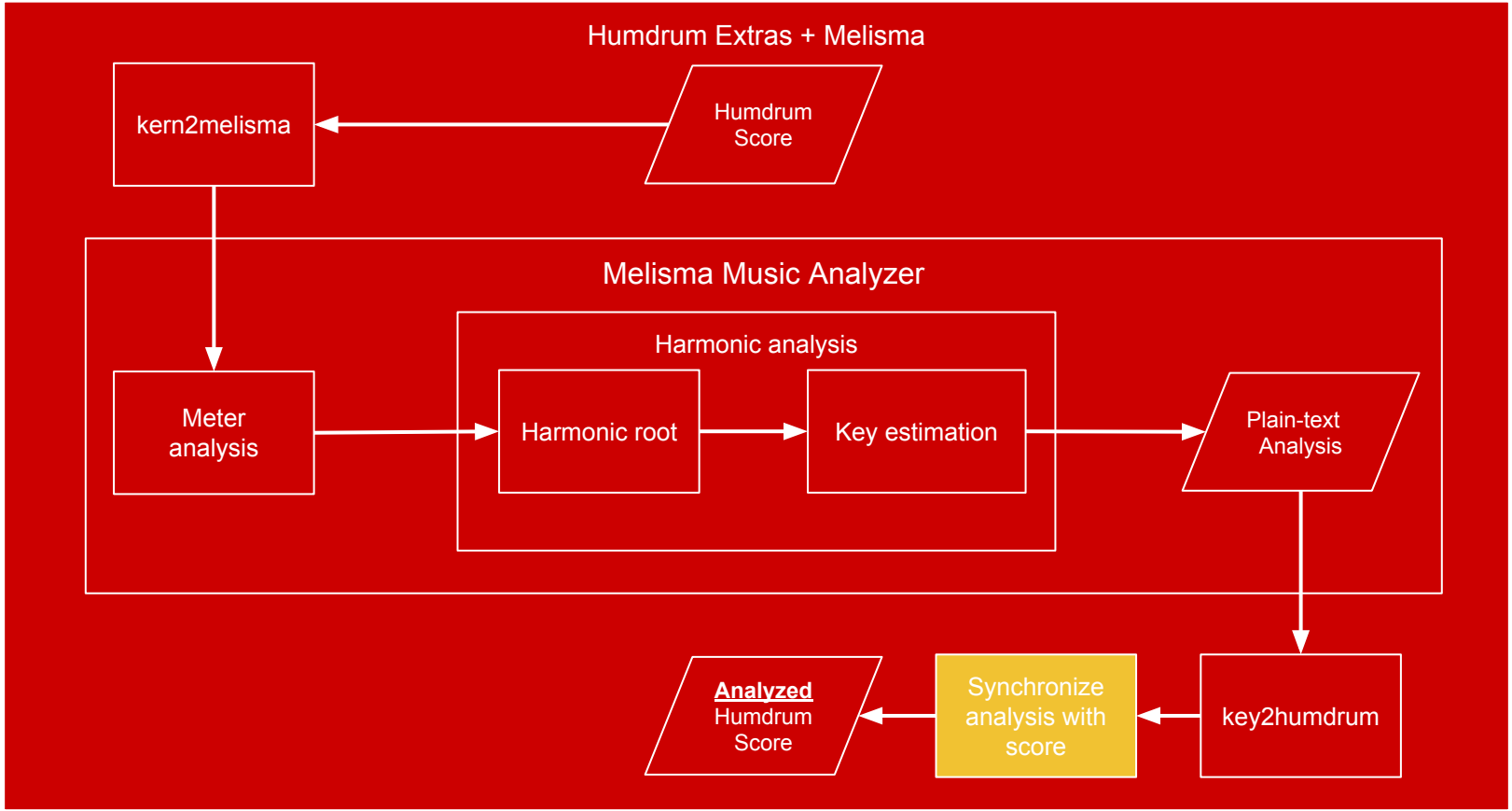

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Universitat Pompeu Fabra Barcelona

Thank you

Backup Slides

Isn’t there any more recent research than that?

Isn't there any more recent research than that?

Sort of, but not entirely.

They are considering a pre-processed music score,
especially ignoring the difficult problem of non-harmonic tones

They output a different kind of label notation

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**harm parser

```
^(
    (?P<accidental>          # Named group _accidental
    [#-]{0,2})

    (?P<root>                # Named group _root_
     i|ii|iii|iv|v|vi|vii|   # Minor mode degrees
     I|II|III|IV|V|VI|VII|   # Major mode degrees
     N|Gn|Lt|Fr|Tr)          # Special chords

    (?P<attribute>           # Named group _attribute_
    [o+]?)

    ((?P<intervals>          # Named group _intervals
    \d+|[mMPAD]\d+|          # Detect minor, Major, Augmented or Diminished intervals
    AA\d+|                   # Double-augmented intervals
    DD\d+)                   # Double-diminished intervals
    *)                       # Not a limit on how many intervals can be added

    (?P<inversion>           # Named group _inversions_
    [b-d]?)                  # Only third inversions possible so far

    (\[                      # Open brackets
    (?P<alternative>         # Named group _alternative_
    ([^\[^\]])+)             # Match at least one time for any expression inside brackets
    \]                       # Close brackets
    )?                       # If no alternative expression, then no brackets should appear at all

    (/                       # Slash implies a secondary function
    (?P<secondary>           # Named group _secondary_
    ([\s\S])+)               # Get all the expression after the slash symbol
    )?                       # If no secondary function, then the slash symbol should not appear
)$
```